MIT'S MAGAZINE OF INNOVATION

TECHNOLOGY REVIEW

SEPTEMBER 2003

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CAN THIS JET SAVE AIR TRAVEL?

Inside Boeing's plans to build the world's most efficient airliner

A LOOK INTO THE O.R. OF THE FUTURE

Location Services: New Hope for Wireless

HP's Gamble to Revolutionize Computing

A Safer Alternative to Biopsies

PLUS

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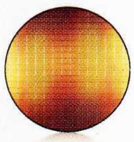
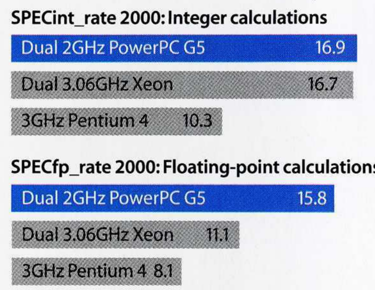
The world's fastest personal computer.

The new Power Mac® G5 is here. It's the world's fastest* personal computer, and the first with a 64-bit processor. At its heart are two revolutionary PowerPC G5 processors, running at speeds up to 2GHz. And since these are 64-bit processors, they can access up to 8GB of memory in the Power Mac G5, which is double the 4-gigabyte memory ceiling of every other PC in the world. The G5 processors also have the world's fastest frontside bus, running at 1 gigahertz, which gets data to the processor almost twice as fast as the 533-megahertz bus found in the next-fastest personal computer (a dual 3.06GHz Xeon machine).



The PowerPC G5 chip. The world's first 64-bit processor for personal computers.

In side-by-side speed tests using industry-standard benchmarks, the dual 2.0-gigahertz Power Mac G5 is up to 41% faster than both the fastest Pentium 4 and dual-processor Xeon workstation. And the results get even better when using real-world applications: the new Power Mac G5 runs Photoshop more than twice as fast as the fastest PCs. Further tests reveal there are similar gains across a wide range of applications, from music and video to science and mathematics.



Independent tests show the Power Mac G5 edges out the competition on integer and blasts past them in floating-point.

IBM

The PowerPC G5 chip is based on IBM's highest performance 64-bit supercomputer processors.

Impressed? We haven't even touched on the Power Mac G5's other features. Like its ultrahigh-bandwidth system architecture, featuring AGP 8X, PCI-X, FireWire® 800, Gigabit Ethernet, up to 500 gigabytes (yes, that's half a terabyte) of internal Serial ATA storage and a SuperDrive™ for DVD authoring. All inside a stunning, professional-quality aluminum enclosure that features four discrete computer-controlled cooling zones for whisper-quiet operation. Together, they make the Power Mac G5 a true breakthrough in personal computing.


G5
G5

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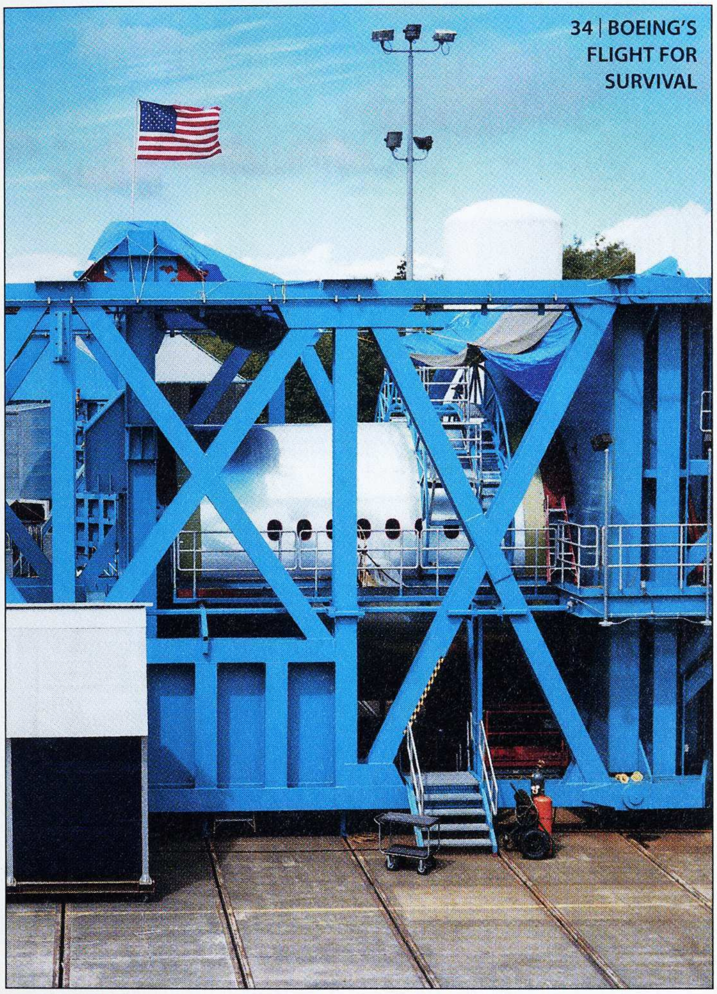

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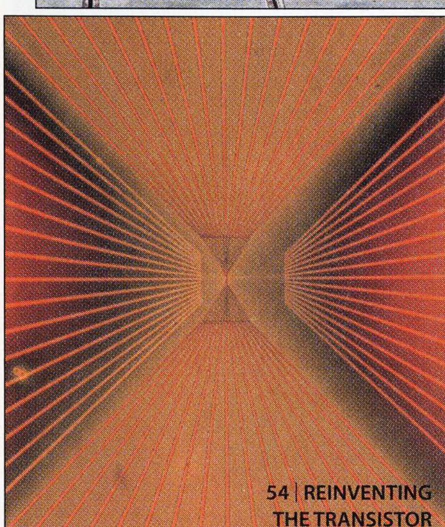

On the cover: Boeing's 7E7. Illustration by John MacNeill.

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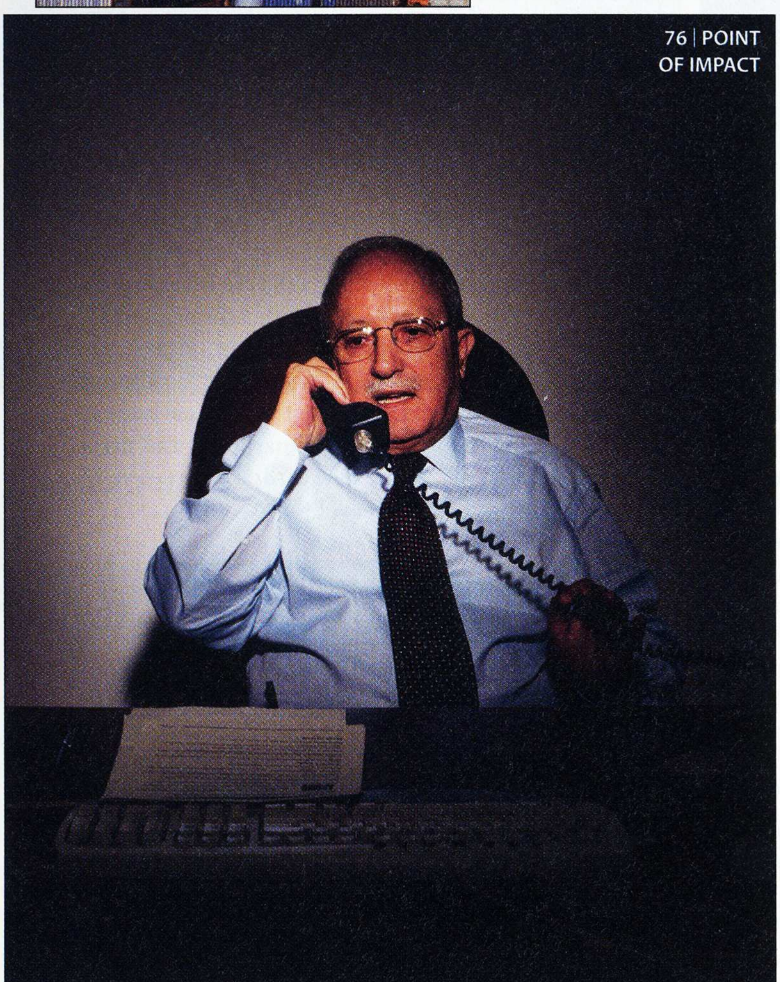

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BOEING'S SLOW-DEATH HAND

If you've ever played poker, you've probably been dealt a "slow death" hand—cards just good enough to keep you betting but not good enough to win. You typically sense the truth, but delude yourself that you'll get lucky, and so keep shoveling chips into the pot. Then, sure enough, the day of reckoning comes—and you realize you should have jettisoned the cards early on and waited for a new and better opportunity.

If ever a company was playing a slow-death hand, it's Boeing. The aerospace titan, once a symbol of innovation, seems to be sticking increasingly with noninnovative, behind-the-times aircraft and watching its previously commanding lead in passenger airliners be whittled away. Consider the gruesome statistics: leading rival Airbus has soared from a 19 percent market share a decade ago to 40 percent last year. With 1,500 new plane orders on the books versus Boeing's 1,100, the European aerospace consortium is set to grab the top spot in just a few years. By 2013, Boeing could be staring at a meager 30 percent share, according to an assessment from aviation industry consultants the Teal Group.

Unless, that is, Boeing innovates its way to reversing this trend. Which is why as a poker player, frequent airline passenger, and student of the research and development imperative to produce new products (and not just incremental improvements on existing ones), I urge Boeing to fold its slow-death bet on its current fleet and deal itself some fresh cards by building the proposed 7E7, aptly dubbed the Dreamliner.

The challenge, and promise, of constructing this state-of-the-art plane are laid out in a compelling story by *TR* senior editor David Talbot, "Boeing's Flight for Survival" (p. 34). Talbot tells us the 7E7 could roll off production lines and onto runways by 2008—marking Boeing's first new commercial-jet design since the 777 debuted in 1995. The Dreamliner is not especially radical on the surface: a mid-size craft that can carry between 200 and 250 passengers and will set no speed records. But thanks to a wealth of technological improvements that range from increased use of lightweight composites and electronic controls to networked sensors able to diagnose structural problems well before they become critical, the plane could set a benchmark for efficiency and profitable operation.

Boeing says the aircraft will essentially match the speed and range of large jets like the 747; what's more, it will burn 20 percent less fuel than other mid-size jets and save millions in operating costs over the life of the plane. Its long range and moderate size could enable airlines to open as many as 400 profitable new nonstop long-distance routes.

But even though Boeing is pouring an estimated $350 million this year (roughly half its commercial-jet R&D budget) into the design, it's not at all clear the Chicago-based company will take the plunge. The big fear is that with the cost of introducing a new plane pegged at close to $10 billion, it will be a calamity if Boeing makes the wrong bet. As Boeing's director of technology integration for the 7E7 program told Talbot, "If we get it wrong, it's the end. And everyone here knows that."

But it's fair to ask whether staying the course might be even more dangerous. Earlier this year, the company killed plans for the Sonic Cruiser, a superfast luxury skyliner that would carry the same number of passengers as the 7E7, while promising to knock two hours off a New York to Hong Kong run. If the 7E7 is also dropped, the leading alternative for a "new" plane would seem to be a next-generation 747 that would be slightly larger and all of 5 percent more efficient than the last batch of 747s that rolled out in 1989. I hate to say it, but you just don't get much more slow death than that.

If the 7E7 is axed, the leading alternative for a "new" plane would be a next-generation 747 all of 5 percent more efficient than those built in 1989. You don't get much more slow death than that.

Boeing's board of directors will meet early next year to decide the 7E7's fate. But I'm wondering, why wait? We've entered an era of air travel where operating reliability and efficiency are the watchwords—even more important than things like passenger load and speed. The 7E7 would likely be the world's most efficient big passenger jet, and the one best attuned to these times. As such it offers new hope to airlines struggling to increase profit margins—and marks Boeing's best bet to play some new cards and preserve its lead. *—Robert Buderi*

FAREWELL, SETH SHULMAN

A good friend and great journalist is leaving the magazine—at least temporarily. This month marks the last appearance of Seth Shulman's "Owning the Future" column. For nearly three years, Seth has offered penetrating and entertaining insights into our intellectual-property system—putting *Technology Review* at the heart of the debate on this vital topic. We will miss him, and greatly look forward to his writing feature articles for us, which is something at which he is also stellar. One of his first *TR* articles, "Toward Sharing the Genome" (September/October 2000), was part of a package named a National Magazine Award finalist. Goodbye Seth—and thanks.


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LETTERS

INSIGHTS AND OPINIONS FROM OUR READERS

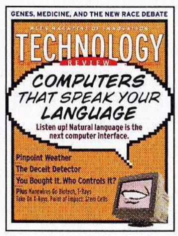
TALKING TO MACHINES

The article "Computers That Speak Your Language" (*TR* June 2003) reports that AT&T has a system that correctly routes more than 90 percent of calls. Unfortunately, when I asked AT&T's customer service line a question it could not understand, it continually asked me to restate my question and offered no opportunity for me to speak with a human. Companies intending to implement this technology should understand that if they cannot accurately forecast the full suite of possible questions, they must provide human assistance as a backup.

John E. McNamara
Maynard, MA

Prompted by this article, I dialed up Amtrak and tried out the $4 million experiment. I was impressed: it had a very nice voice and recognized my speech appreciably well—even when I gave deliberately obscure answers, such as "I don't think so" and "not hardly." The conversation fell far short of casual, though, as the voice kept telling me what things were best to say, interrupting me, and stepping on my words. I'm glad this effort is making headway, but I'll believe in the technology when I can tell my personal digital assistant to reschedule an appointment without taking it out of my pocket.

Keith Rowell
Atlanta, GA



"I'll believe in [speech recognition] technology when I can tell my personal digital assistant to reschedule an appointment without taking it out of my pocket."

STEM CELL ETHICS

The responses of Geron president and CEO Thomas B. Okarma in "Cloning, Stem Cells, and Medicine's Future" (*TR* June 2003) exemplify all that is wrong in the discussion about the use of stem cells in biomedical research. There is no sound scientific basis for research that is destructive to human embryos, natural or cloned. Okarma's suggestion that only cloned embryonic stem cells will allow us to discover disease-causing genes denies a rich history of beneficial disease research with nonembryonic cells. Okarma's statements take advantage of the hope of people who yearn so desperately for cures that they will overlook moral and ethical objections because they are told that the science is sound and the research will be effective.

James L. Sherley
Biological Engineering Division
MIT
Cambridge, MA

Okarma makes it sound like the end of the world if we can't start using embryonic stem cells to develop cures for various diseases. Your interviewer rightly pointed out that there are other, morally unobjectionable, sources of stem cells. In fact, unlike embryonic cells, nonembryonic stem cells have already seen some remarkable early successes, which Okarma seems to have rejected. Moreover, even if donor embryos are "surplus," it doesn't mean they are any less human. Killing them for the sake of research cannot be justified.

Robert B. Austenfeld Jr.
Hiroshima, Japan

DETECTING DECEIT

The story about a newfangled lie detector ("The Deceit Detector," *TR* June 2003) was very likely misguided. Relating any physiological reaction to lying by the human subject is questionable. That connection is fraught with error, misinterpretation, and ambiguous causes; that's why psychophysiologists who have been doing research in the area for decades doubt if there is any identifiable physiological "signal" for deception. Despite this, physical scientists continue to propose new methods of measurement, hoping they will fix up the discredited premise of the lie detector machine. This is a classic case of physical scientists (among whom I count myself) ignoring the work of behavioral scientists, who have a great deal to say about deception detection. Our hallowed intelligence agencies have made mistake after mistake by assuming that these machines are incontrovertible.

Bernard R. Foy
Santa Fe, NM

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PROVING HUMANITY

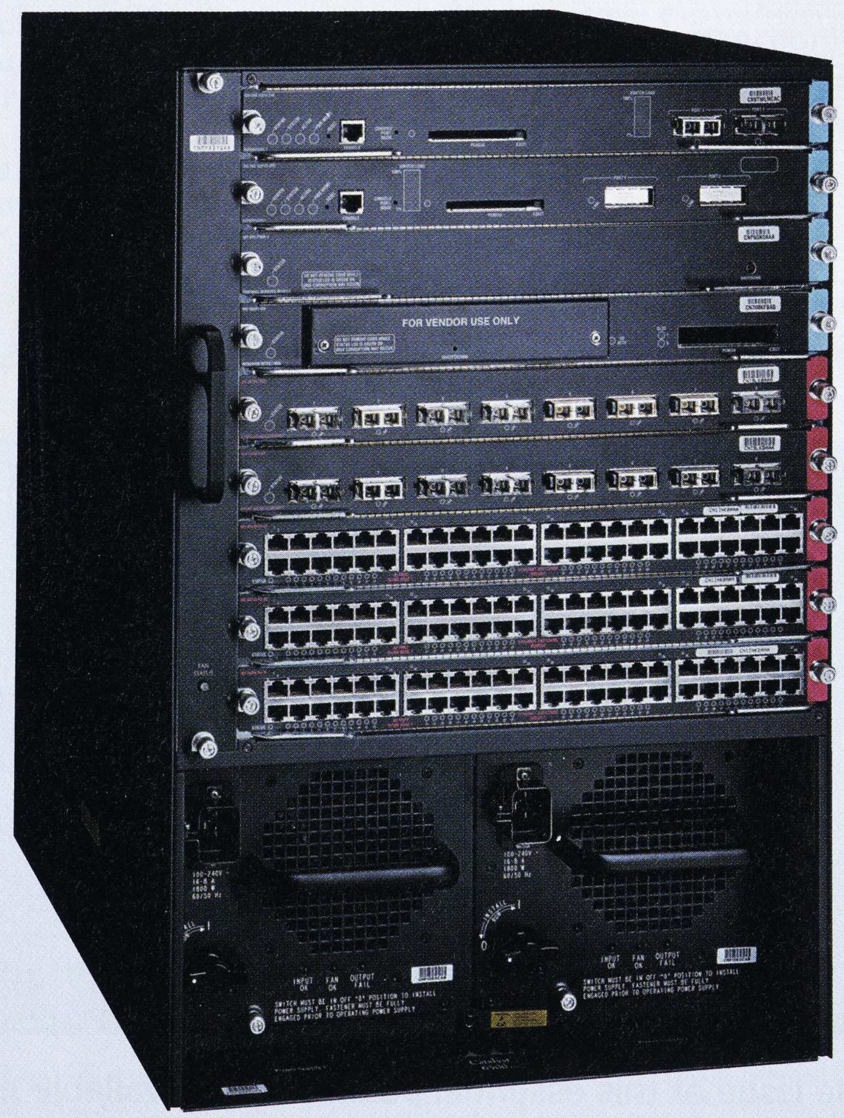
Simson Garfinkel's diatribe against "captchas," where e-mail services test to see if you are a human before allowing you to sign up ("Excuse Me, Are You Human?" *TR* June 2003), misses one very important point: these services are free! If you agree with Garfinkel that these tests could become such a problem as to be "deeply offensive," then I suggest you pay for your e-mail service and avoid the whole situation.

Jerry Dawson
Portland, OR

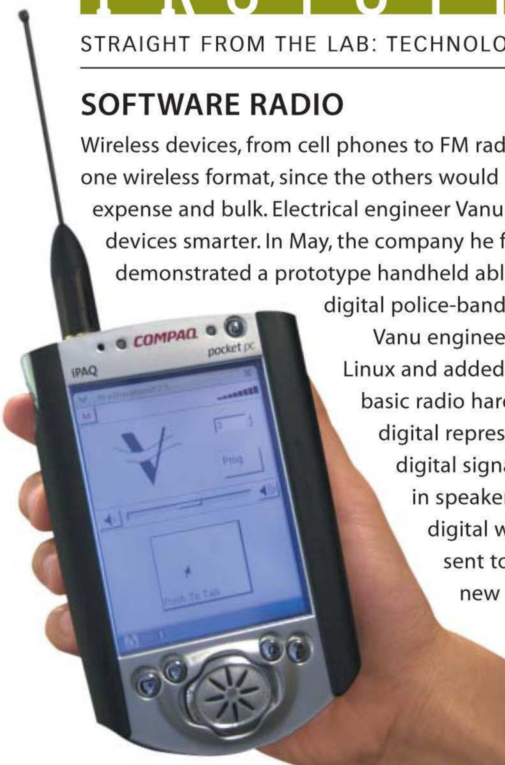
Corrections: While there is an MIT Electrical Engineering 6.270 class in which robots compete, Michael Schrage's June 2003 column, "Amateur Innovation," should have cited "MIT's famed Mechanical Engineering 2.70 competition."

A caption in the June "Visualize" article "Garbage into Oil" should have stated that the turkey-parts-and-water slurry is subjected to a pressure of 50 atmospheres.

I AM A CISCO CATALYST 6500.



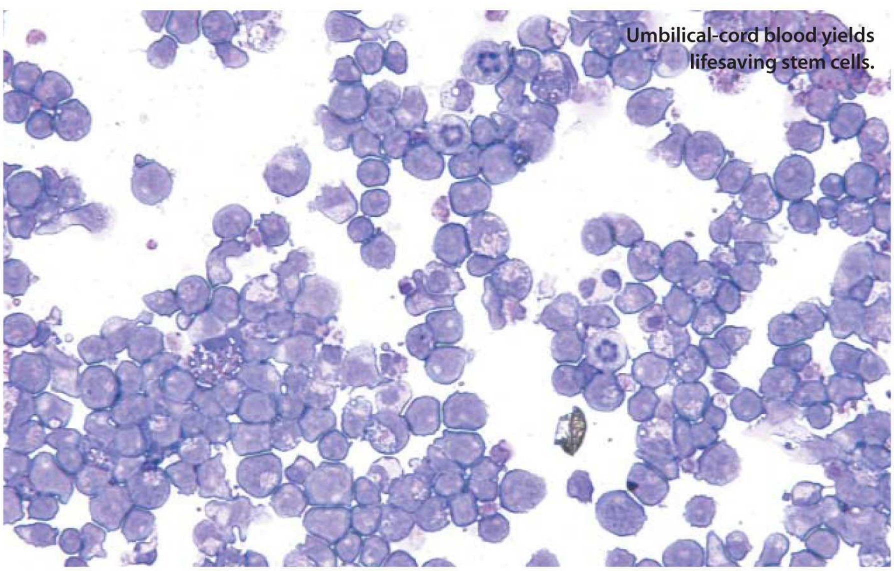
SOFTWARE RADIO



Software enables wireless multitasking.

Wireless devices, from cell phones to FM radios, are effective but dumb. Most handle only one wireless format, since the others would require different radio components, adding expense and bulk. Electrical engineer Vanu Bose is using software to make wireless devices smarter. In May, the company he founded and heads, Cambridge, MA-based Vanu, demonstrated a prototype handheld able to send and receive both walkie-talkie and digital police-band signals.

Vanu engineers started with a Hewlett-Packard iPaq running Linux and added a custom expansion pack. The pack contains basic radio hardware, plus electronics that convert signals into digital representations. Vanu's software then decodes the digital signals and sends sound output to the iPaq's built-in speaker. In reverse, transmissions are encoded into a digital waveform particular to the desired format and sent to the radio hardware for transmission. Adding a new format requires only a software upgrade. The company hopes to commercialize the software for use by police and fire departments within 18 months; consumer products that could incorporate cell-phone, pager, and wireless-data functions are "down the road," Bose says.



Umbilical-cord blood yields lifesaving stem cells.

CANCER CURE SUPPLIER

For tens of thousands of U.S. cancer patients each year, bone marrow transplants offer the best hope for a cure. But as many as 60 percent of patients cannot find donors who are genetically compatible. A new technology created by Gamida-Cell in Jerusalem, Israel, could improve those odds. The technology takes advantage of the fact that banked blood from newborns' umbilical cords, which contains blood-producing stem cells, can offer a better chance for a match than the adult bone marrow most patients receive. But umbilical-cord blood contains relatively few stem cells—only enough to aid recipients weighing less than 50 kilograms. Gamida-Cell has developed a chemical that significantly increases the number of stem cells in cultured cord blood. If all goes according to plan, the company will produce stem-cell-enriched blood itself and sell it as a transplant product, starting as early as 2006. Human trials of the approach have already begun at the University of Texas's M. D. Anderson Cancer Center.

RIDE THE BUS

Bus riders in Boulder, CO, who find it difficult to navigate the mass transit system may soon be able to tear up their maps and schedules and use handheld computers instead. Researchers at the University of Colorado at Boulder, working with Boulder-based software firm AgentSheets, are combining various technologies in a bid to restore independence to the cognitively disabled; eventually tourists might also use the system. Each traveler has a handheld computer and a cell phone. The handheld uses the phone to download Global Positioning System data transmitted by city buses, then determines the best route to the user's destination. Software analyzes bus speed and direction and steers the user to the right bus, using arrows, images, and voice prompts. Future versions may combine GPS, cellular, and processing capabilities, eliminating the need for two separate devices.

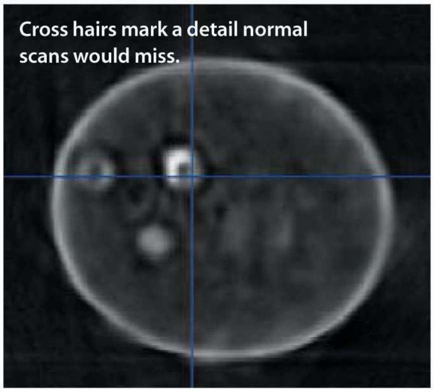
ACOUSTIC IMPLANT

Remon Medical of Caesarea, Israel, is adapting a sound-based underwater communication technique to monitor bodily functions and even administer drugs. Remon's tiny acoustic telemetry device, the size of a grain of rice, has no antenna or other wires and can be implanted deep in the body. Similar devices that use radio-based signals must be implanted a few millimeters under the skin or, if placed deeper, paired with a controller near the skin for communication and power. Remon's device is charged remotely using ultrasound: a membrane stretched across a hole in its custom transducer converts sound waves to electricity. By using a flexible, micrometer-thin titanium membrane, instead of a rigid surface, Remon boosted the transducer's efficiency 1,000-fold. The firm's first products are sensors that measure pressure in the arteries of patients with congestive heart failure or abdominal aortic aneurysms, which affect more than seven million people in the United States.

Future devices might release drugs. Remon has begun human testing and hopes to go to market in 2005.

A tiny implant monitors the body's depths.

COURTESY OF REMON (ACOUSTIC IMPLANT); COURTESY OF GAMIDA-CELL (CANCER CURE); COURTESY OF VANU (SOFTWARE RADIO)



Cross hairs mark a detail normal scans would miss.

ULTRAFINE ULTRASOUND

Every year nearly one million unnecessary biopsies are performed in the United States, while tens of thousands of tumors go undetected. This is because diagnostic imaging techniques like x-ray mammography and ultrasound can't resolve features smaller than about five millimeters. Now biomedical engineers Vasilis Marmarelis and Tae-Seong Kim at the University of Southern California have developed an ultrasound system with 10 times better resolution. It uses an array of dozens of transmitters, each .4 millimeters on a side, to send ultrasonic pulses through tissue to a matching array of sensors on the opposite side. A computer generates images of the tissue based on the time delay and shape of the received sound waves. Resolution is high because the hardware elements are so small, and because transmitted signals carry more information than the reflected signals used in conventional ultrasound. The system will enter human trials this fall, says Marmarelis, and the researchers hope to partner with medical-imaging firms.

TEXT, LIES, AND VIDEOTAPE

A picture may be worth a thousand words—but even a few words can help sort a thousand pictures. At Siemens Corporate Technology in Munich, Germany, engineers Andreas Hutter and Joerg Heuer have developed software that analyzes video sequences and automatically generates text descriptions of all the moving objects within them. Instead of classifying an object in a parking garage as a person—a difficult task—the software could indicate that a "triangle" (legs) with a "brown top" (hair) traced a certain trajectory. Armed with a text database, security personnel could then search for a car thief with brown hair walking along a certain path just by typing in a few keywords. The Siemens approach, which is compatible with digital-video data standards and could be commercially available in three to five years, is faster and more reliable than training a computer to search videos specifically for a walking person, says Hutter. And the computer doesn't need to be reprogrammed if security also wants to look for something else, say a particular car: a search for a "red rectangle" with "circles" will do.

A one-armed coaster gives a personalized ride.

ROBO RIDE

Imagine experiencing the upside-down thrills and G forces of a 100-meter-high roller coaster, but without tracks and within a space only seven meters high. That's the idea behind Robocoaster, a programmable robot arm that can carry two passengers through loop-the-loops and barrel rolls at accelerations of almost twice the force of gravity. The ride, developed by Robocoaster of Warwick, England, and Kuka Roboter in Augsburg, Germany, is a modified cousin of the giant robot arms that handle everything from heavy lifting to spot-welding on automotive-factory floors. "Riders can choose from five levels: gentle, fun, fast, turbo, and extreme," says Robocoaster president Gino De-Gol. That versatility makes the ride exciting for teens but still accessible to small children and senior citizens. Robocoasters are being tested at three amusement centers in the United States, Brazil, and Denmark, and could show up next year at major theme parks, says De-Gol.

COURTESY OF DRIVEDIAGNOSTICS.COM (DRIVER PROFILER); COURTESY OF ROBOCOASTER (ROBO RIDE); COURTESY OF TAE-SEONG KIM AND VASILIS MARMARELIS (ULTRAFINE ULTRASOUND)

DRIVER PROFILER

Horrible driving seems to be reaching epidemic proportions. So DriveDiagnostics of Jerusalem, Israel, is aiming to give vehicle owners and insurers direct feedback on drivers' performances. Next year, the company plans to begin marketing a device, eight centimeters in diameter, that sits on the dashboard and monitors every move the vehicle makes using accelerometers to measure the forces on the car. Different combinations of forces correspond to different events, and algorithms deduce whether the driver is braking suddenly or taking a corner sharply. The software examines a journey's worth of events and correlates them with one of 30-odd driver profiles, such as "tired," "drunk," or "inexperienced." Although the device will flash a red warning light when a bad move is made, the target market isn't drivers but those who want to enforce better driving, such as parents of new drivers, car fleet managers, and insurance companies, who could review drivers' performances after the fact.

Lousy drivers can't hide from this device.

MICHAEL SCHRAGE

IN THE WEEDS

THE CUSTOMER AS ENEMY

Thanks so much for reading my column, but I have to ask: are you a thief? I need to know because *Technology Review* reserves the right to sue you if you reproduce this intellectual property without our express, written approval. By the way, this publication uses "smart paper" with patented steganographic technologies explicitly designed to track unauthorized scans or photocopies of my column.

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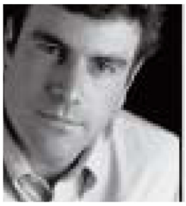
Just kidding, of course. Then again, such humor may be less appealing if you've seen those full-page ads in the *New York Times* in which the record industry threatens legal action against anyone who downloads unauthorized music from the Internet. Or if you've been the victim of a copy protection scheme that prevents you from playing a legitimately purchased DVD. In fact, the digital era is giving birth to one of the most remarkable transformations in business history. The Customer is King? No, the Customer as Enemy.



Increasingly, innovators are trying to constrain, curtail, confine, and control their customers as opposed to cost-effectively creating greater choices for them *(see "You Bought It. Who Controls It?"* TR *June 2003)*. For understandable but controversial reasons, innovators invest heavily in techniques and technologies that treat customers as potential thieves and competitors. People procuring innovative products and services are discovering that their ability to pay matters far less than their willingness to behave the way vendors want.

The problem, alas, is that innovators and their customers often have profoundly different notions of appropriate behavior. Your seemingly reasonable desire for a backup copy of your new software program or DVD may be your vendor's very definition of intellectual-property theft. Shame on you? Or shame on them? Caveat adapter!

Hollywood and the music industry, for example, continue to concoct a growing variety of clever technical schemes to ensure that their intellectual property is not bootlegged, stolen, or inappropriately copied. DVDs, the digital product with the fastest-growing market in consumer electronics history, are encrypted by the Content Scrambling System to ensure they can't be copied or played outside the region in which they are purchased. Computer-savvy DVD owners can find descrambler software on the Internet, but there have been dark mutterings about secreting software on DVDs that would interfere with the ability of computers to function if they used these programs. In other words, the "crime" would come with a built-in punishment.

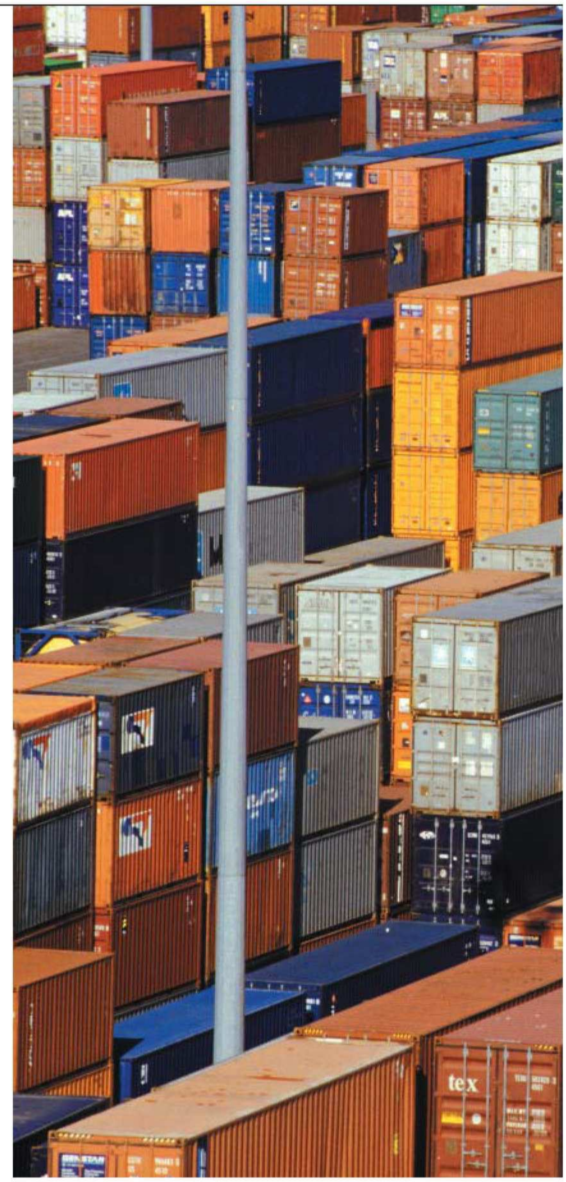
The Recording Industry Association of America, meanwhile, has won the right to compel Internet service providers to divulge the names of users who share copyrighted music over peer-to-peer networks. And as any Microsoft customer knows, you don't actually own digitized intellectual properties like music, movies, or software, anyway—you "license" them under explicit terms and conditions. Violating the license can be a crime. And as ever more sophisticated remote-monitoring technologies kick in, Sony or Microsoft's ability to seek out miscreants and extract legal damages is dramatically improving.

Unsurprisingly, consumers and even businesses are starting to cry "Foul!" Software licensing terms are but one battleground. Fortune 1,000 firms worldwide, for example, are painfully familiar with their software vendors' abilities to track who's using what features and functionality. Not only does unauthorized use of the software assure a call from an aggressive lawyer, but the ability to see how many employees are still using version *n* lets vendors launch a storm of upselling whenever they decide it's time to "encourage" their corporate clients to upgrade to version *n+1*. Many CIOs now point to the onerous licensing terms imposed by Microsoft and other vendors as a direct cause of the rise in corporate use of open-source Linux.

Your seemingly reasonable desire for a backup copy of your new software program or DVD may be your vendor's very definition of intellectual-property theft. Caveat adapter!

As intellectual property increasingly becomes the critical value-added component of competitive innovation, the fear that it may leak or seep away through inappropriate copying is completely understandable. Similarly, wrapping services such as remote monitoring and tracking around the products companies sell may seem like an eminently reasonable way of maintaining ongoing relationships with customers.

But the business consequences of "customer-as-criminal" mindsets are inevitably perverse. For customers, the prospect that vendors are looking over their shoulders to track whether this copy is authorized and that usage is approved creates a powerful *disincentive* to embrace innovation. Antipiracy, anticopying, pro-monitoring licensing agreements and the invasive technologies used to enforce them make it riskier than ever to be an innovation adopter. The customer may not always be right, but she ain't always a thief, either. Honest. TR



CONTAINING TERROR

Electronic seals and tracking efforts boost cargo security

The cargo container—that ubiquitous truck-sized box that carries goods around the world—could be the ultimate poor man's missile. Each year more than 48 million loaded cargo containers move between the world's seaports. But of the six million that arrive in the U.S., only 5 percent have their contents visually inspected or x-rayed, opening the possibility that terrorists could use them to smuggle in nuclear material, explosives, or even themselves. Many of the world's ports are joining a U.S.-led effort to manually inspect containers considered high risk; but at the same time, a host of technologies are being readied to plug this security hole.

It's a big job that starts with small electronic seals. This spring, Savi Technology of Sunnyvale, CA, and 65 technology companies and shipping industry partners concluded the first test of a new class of electronic seals that both track containers and detect intrusions. Affixed to a container's main latch, the seal has two functions. First, it serves as a radio frequency identification tag, allowing a container's movements to be recorded automatically when it passes tag readers on loading cranes and port gates or in distribution facilities. That's a technology already common in military containers, and it was recently used during the Iraq war.

But the new seals go a step farther, detecting break-ins. Opening the container breaks a magnetic field surrounding the seal; this event, and the time it took place, are recorded on a memory chip. The next time a breached container passes a tag reader, an intrusion alarm is automatically triggered, flagging the container for inspection.

The test was successful enough that several thousand seals have already been deployed to various government agencies and major shippers. According to Lani Fritts, a vice president of business development for Savi, the same consortium of 65 companies has now begun a second global field test that will ultimately involve 5,000 containers fitted with the electronic seals. What's more, the infrastructure being set up by the consortium will communicate automatically with government agencies like U.S. Customs and Border Protection.

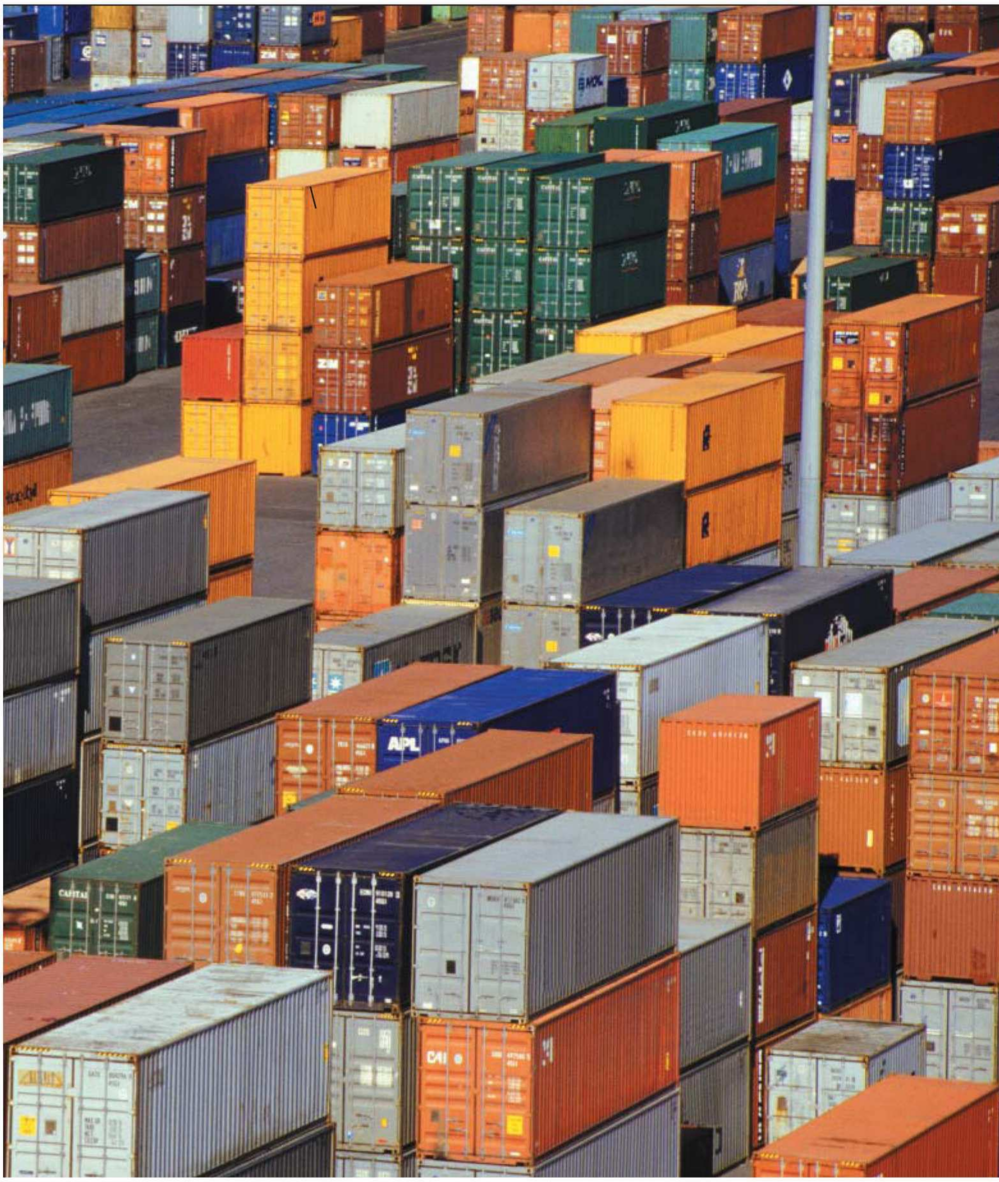
Some of the containers in this new batch are being equipped for continuous communication; Savi is working with Qualcomm of San Diego, CA, to connect the seals with transponders that can communicate with satellite tracking systems, sending alerts in real time no matter where a container is located—on the high seas, at port, or bumping along on a truck chassis or railcar. Because continuous real-time communication is more expensive—how much more is not yet clear—the initial tests involve high-risk cargo like hazardous materials, or high-value cargo such as pharmaceuticals.

The cargo industry's next goal is more ambitious: to introduce the world's first "smart containers," with multiple sensors manufactured into them. Savi is working with CIMC of Shenzen, China, the world's largest cargo container manufacturer, to design and develop the first prototypes by the end of this year. If all goes well, these next-generation containers could be in commercial production next year.

A smart container made from scratch will do much more than detect if its main seal has been breached. For example, if an intruder tries to cut or drill through its sides, light and motion sensors inside can communicate with the seal, which can transmit a tamper alert either via the Internet or by setting off a light or sound alarm. In the future, additional sensors could detect chemicals, radiation, and

Securing Containers

GROUP	TECHNOLOGY
Savi Technology (Sunnyvale, CA)	Electronic seals and smart cargo containers
NaviTag Technologies (North Quincy, MA)	Electronic seals and tracking devices that use satellites
Isotag (Addison, TX)	Chemical-based intrusion detection using seals and handheld sensors
Argonne National Laboratory (Argonne, IL)	New detector to find nuclear materials in containers
MIT (Cambridge, MA)	Radiation detector with imaging capability



Affixed to cargo containers (left), electronic seals (top) report intrusions to handheld devices. A prototype detector array (bottom) makes images of radioactive objects.

GETTY IMAGES (CONTAINERS); COURTESY OF SAVI TECHNOLOGY (SEAL); COURTESY OF MIT (DETECTOR)

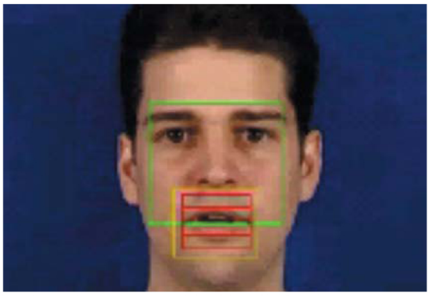
the residue of explosives. Such a container would have "a 'mayday' capability, in which it can recognize an unacceptable condition and report its identity, location, and condition," says Michael Wolfe, principal of the North River Consulting Group of North Marshfield, MA, which advises government and industry on security technologies.

But even the smartest containers may still need inspections: an inspector who learns that a container has been breached might need to find out what has been placed inside. Today's technologies, however, are inadequate for detecting the biggest threat: a nuclear bomb or radioactive "dirty bomb."

One possible solution: a gamma ray detector with an additional imaging component that reveals the shape of the materials emitting radiation. That's what a group led by Richard Lanza, a nuclear engineer at MIT, has prototyped. It's an array of small detectors that collect gamma rays and produce a fine energy spectrum that gets processed into a faint image of the radiating object.

This allows inspectors to identify innocent materials that give off small amounts of radiation—like certain medical supplies or objects made from granite—without wasting time on manual inspections. Prototypes of the detectors are currently being tested at the Lawrence Livermore National Laboratory in Livermore, CA.

Deployment will depend on the outcome of these tests, but the MIT device is part of an ambitious vision for the future of nuclear-explosives detection, says Richard Wagner, a physicist at Los Alamos National Laboratory who is helping evaluate new detection technologies for the federal government. "Eventually we hope to deploy hundreds of thousands of detectors," everywhere from seaports to highway border crossings, he says. Such a grand scheme might cost \$10 billion; but the cost of detecting a nuclear bomb, clearly, is much cheaper than the cost of letting one through.—*Amitabh Avasthi*



Intel's system isolates mouth movements (red).

DIGITAL LIP READER

INTERFACES | Speech recognition is a long-promised technology that's finally beginning to deliver. But today's best systems tend to fail when the speaker is in a noisy spot. To fix this problem, researchers are adding lip-reading to the mix.

While people rely on mouth shapes all the time to interpret speech, lip reading is no simple task for a computer. For one thing, each shape can correspond to several specific sounds. To make matters worse, mouth movements begin as much as 120 milliseconds before a sound is uttered. Humans can use other cues such as sentence context and facial expressions to overcome these difficulties, but until recently, computers lacked the processing power to do so.

Now groups at Intel, IBM, and other institutions are modifying language-processing programs to link each vocal sound to several possible mouth movements, allowing the software to make a best guess about what's being uttered. In tests in noisy environments, adding visual information boosted speech recognition accuracy from 20 percent to 75 percent, says Ara Nefian, a senior researcher at Intel Research in Santa Clara, CA.

Initially, this is likely to be most useful to doctors and others working in noisy locations who need better accuracy from office dictation software. With this audience in mind, IBM is building a tiny camera into the boom microphone that comes with existing speech recognition software. Further down the road, researchers envision the day when your car dashboard might have a camera peering at your lips for voice-actuated controls, or your cell phone might watch what you say. —*Wade Roush*

SURVEILLANCE WITH PRIVACY

Programs would sift private data while protecting names

SOFTWARE | There's been plenty of public debate about allowing the government to seek patterns in disparate databases—to "connect the dots"—to thwart terror attacks. One problem for investigators is that many of these databases, which store information such as private phone records and credit card statements, are closed to routine government scrutiny. The Information Awareness Office at the U.S. Defense Advanced Research Projects Agency is attempting to demonstrate that private databases can safely be plumbed if the day comes when privacy laws are changed to allow access to them *(see "Total Information Overload,"* TR *July/August 2003).* If one DARPA-funded project at the Palo Alto Research Center in California is successful, it could result in technology that lets government intelligence analysts find patterns in data while forbidding access to details about individuals.

"The government wants to have predictive models so it can build up evidence of a significant future attack. It doesn't need identifying access to anybody to build up these models," explains Teresa Lunt, a computer scientist at PARC. She's developing a kind of "inference firewall" designed to sit between government analysts and data sources such as phone logs or academic records, anticipating queries that seem harmless but would unintentionally reveal details about a particular person. If there were only one woman taking a college course, for example, asking the average grade of all the women in the course would reveal that woman's grade. Lunt's software instantly blocks such queries.

The $3.5 million, three-and-a-half-year project is one of several DARPA is sponsoring to minimize privacy violations when and if the U.S. Congress relaxes the laws requiring investigators to obtain warrants before searching private databases. Whether the very existence of privacy protection tools would make such changes in privacy laws more likely is an open question. "Genuine privacy tools should enable the things that people want to do—commerce, communicate, research, and publish. A privacy tool that simply allows the government to conduct surveillance [more easily] is an oddly Orwellian concept," says Marc Rotenberg, an information privacy expert at the Georgetown University Law Center. But given that U.S. citizens have already absorbed some civil liberties trade-offs since the September 11 attacks, it just might be a concept they're inclined to accept. —*Wade Roush*

Beyond "Information Awareness"

The phrase "Total Information Awareness" gave plenty of lawmakers and citizens pause. Now the U.S. Defense Advanced Research Projects Agency—which coined that term, only to change it to "Terrorism Information Awareness"—is making new additions to the lexicon as it funds research on how to scan private databases, like credit card and phone records, while masking identities.

ANONYMIZATION would scramble identifying information like names, addresses, and phone numbers before data are released to investigators.

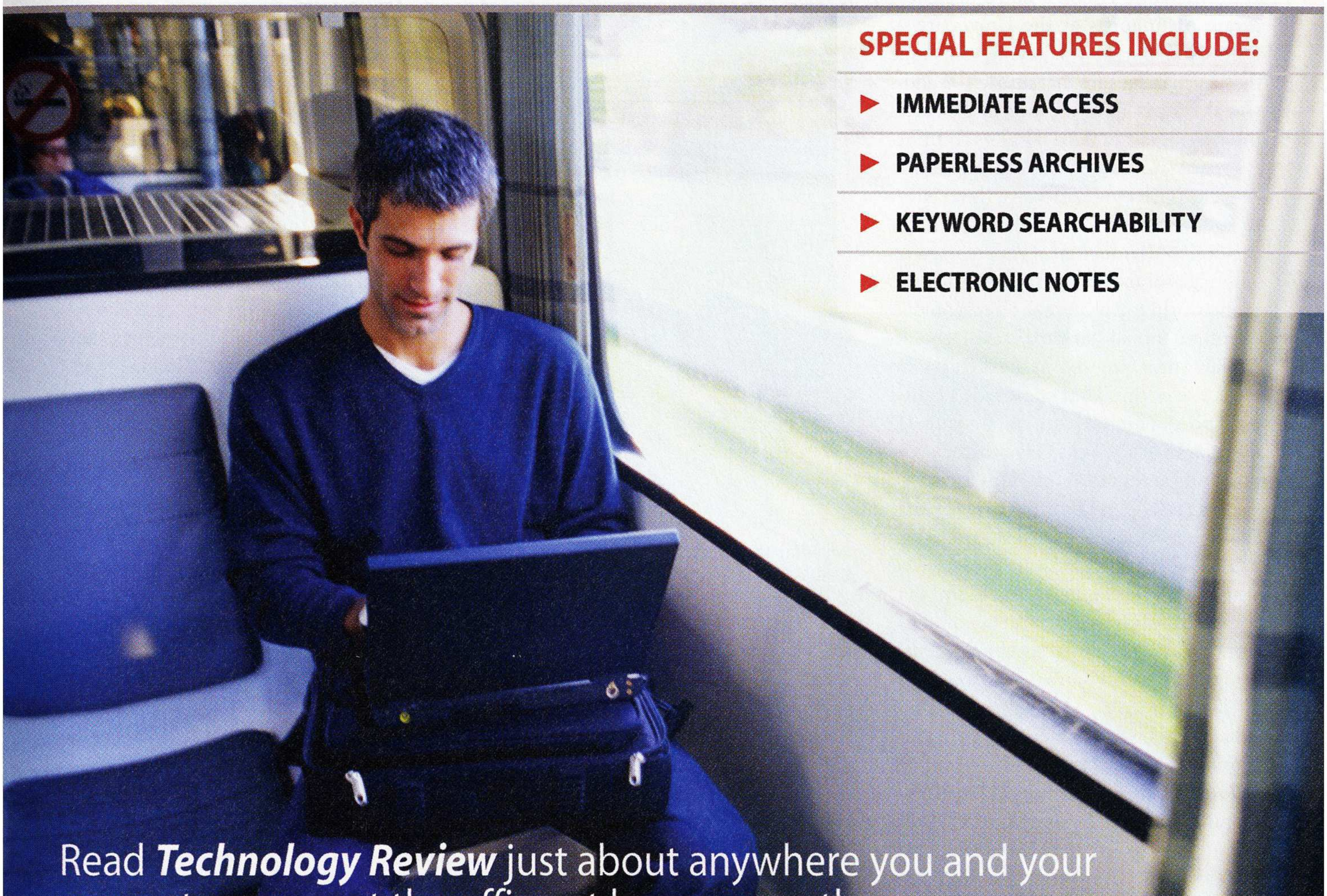
SELECTIVE REVELATION would reveal identifying information only incrementally as criminal patterns emerge from anonymized data, and as legal steps, such as securing search warrants, are taken.

SELF-REPORTING DATA would be wrapped in software or digital watermarks that guard against misuse of private information by tracking who has used the data, and where they have been moved.

IMMUTABLE AUDITS would keep tabs on investigators by distributing records of data access to multiple keepers to prevent alteration or tampering.

PRIVACY APPLIANCES would, among other functions, automatically filter out seemingly harmless queries that might allow investigators to infer the identities of private citizens.

COURTESY OF INTEL RESEARCH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COMPUTERS LEARN NEW ABCs

Efforts to encode the world's written languages will enable a truly global Internet

INTERNET | For tens of millions of people around the world—from West Africa to Southeast Asia to the Middle East—the Internet's not such a friendly place. That's because many of the world's writing systems still aren't encoded in software, which means millions of people can't write e-mail, build Web sites, or search databases in their native scripts. A group of linguists at the University of California, Berkeley, is trying to change that, by making sure that nearly 100 additional scripts have a place in a crucial international standard that lets computers render, process, and send text data.

The university's initiative "is an effort to rectify an oft-overlooked aspect of the digital divide: many scripts used by languages of under five million speakers in the world today are not represented in the international standard," says Deborah Anderson, a linguist at Berkeley who leads the effort. That standard is called Unicode, which assigns a unique ID number to every written character, symbol, and punctuation mark in a written language. The ID numbers mean that characters won't get misinterpreted as data move between software programs or across the Internet—a problem that sometimes shows up as a string of question marks on your screen and can cripple the ability of whole populations to communicate via the Internet. For example, Unicode is enabling radical economic transformations in Vietnam. Before this year, computer and software manufacturers had come up with 43 different ways to encode Vietnamese text, which meant computers couldn't reliably swap data. Then, early this year, the Vietnamese government adopted Unicode as its national standard.

The problem is that the more obscure writing systems are not yet encoded in the Unicode standard. Adding another


YELEN

Encoding the N'Ko script of West Africa could enable an online version of this newspaper.

100 scripts is a big task; only 52 are encoded today. To do the job, Berkeley is recruiting and funding linguists, as well as users of scripts like N'Ko (used in West Africa), Balinese (used in Indonesia), and Tifinagh (used in parts of Northern Africa), to determine how many characters each script contains, design fonts, and guide proposals through a bureaucratic maze of government agencies and computer standards bodies. The benefit will be visible to Internet users like Mamady Doumbouya, a Philadelphia publisher who would be able to offer an online version of his newspaper in N'Ko for the first time. "Without Unicode, it takes so much to set up your computer to read a newspaper in N'Ko," Doumbouya says.

Such changes won't happen overnight. Anderson estimates that the project, launched last year, will take 10 years to complete. Until recently, computer companies sustained the encoding effort, but their interest is dwindling because users of unencoded alphabets represent too small a market. The Berkeley project is part of a larger effort to make the Internet more globally available; already the World Wide Web Consortium has made it possible to register domain names in these new scripts, meaning, among other things, that the URLs of Web sites can reflect the writing systems of the people who own them.

U.S. national security experts are interested, too. Everette Jordan, head of the National Virtual Translation Center, a newly formed U.S. government office that provides foreign-language resources for the intelligence community, points out that "technologically, we're deaf, dumb, and blind if we can't read this stuff." Soon, though, U.S. security agencies and African newspaper publishers alike could rally to a new standard. —*Michael Erard*

Written languages proposed for encoding include (left to right) Naxi, used in parts of China; Syloti Nagri, used in north Bangladesh; Sorang Sompeng, used to write the Sora language in India; and Saurashtra, another script used in parts of India.

COURTESY OF MICHAEL EVERSON (SCRIPTS); MAMADY DOUMBOUYA (NEWSPAPER)


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Introducing IBM DB2 Information Integrator – the brand-new software that turns everything in its path into insight and opportunity: rows and columns, video and e-mail, audio and Web. It works wherever your data lives: Oracle, Microsoft® or IBM. It works in real time, across platforms: Linux,® Windows,® UNIX.® Insight is yours. On demand. Faster than ever. For a DB2 Information Integrator Kit, visit ibm.com/db2/integrate
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TARGET: ROGUE IMMUNE CELLS

DNA-derived vaccine advances on MS

BIOTECH | Drugs for autoimmune diseases like multiple sclerosis, type 1 diabetes, and rheumatoid arthritis provide relief from symptoms but don't address causes. Researchers now hope to change that with an emerging class of vaccines made from DNA that shut down the immune cells that go awry in these diseases. Early results have been so promising that human trials for the first treatment—a multiple sclerosis therapy that made paralyzed mice walk again—will begin early next year.

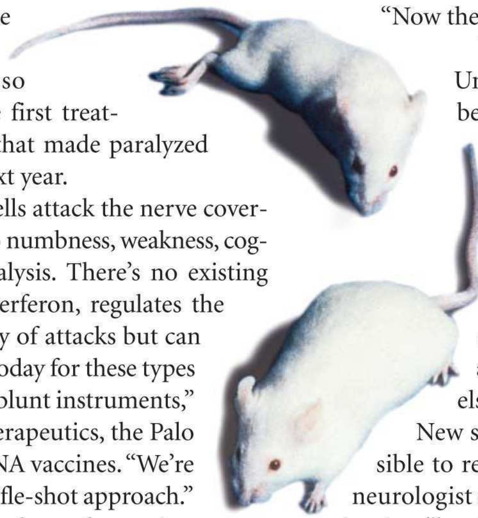
In MS patients, rogue immune cells attack the nerve covering called the myelin sheath, leading to numbness, weakness, cognitive problems, and eventually paralysis. There's no existing cure; a leading drug, called beta-interferon, regulates the immune system to reduce the severity of attacks but can carry severe side effects. "Treatments today for these types of autoimmune diseases are basically blunt instruments," says John Walker, CEO of Bayhill Therapeutics, the Palo Alto, CA, startup developing these DNA vaccines. "We're interested in taking much more of a rifle-shot approach."

Two engineered DNA molecules make up the vaccine; both are taken up by specialized "first responder" immune cells, which are thus transformed into MS-fighting machines. One DNA molecule encodes a protein found in the myelin sheath; the first-responders make this protein, which acts as bait for the rogue immune cells. Once this trap is sprung, the second DNA molecule goes to work. It encodes a protein that switches the rogue cells from a destructive mode to a protective mode.

Lawrence Steinman, the Stanford University Medical Center immunologist and neurologist who developed the approach and cofounded Bayhill, says the strategy has dramatically reduced the severity of the disease in mice—and even made paralyzed mice walk again. "There isn't a mouse we haven't cured," Steinman says. "Now the issue is, can we translate this into man?"

With 350,000 people suffering from MS in the United States alone, that is a critical question. To begin answering it, the company has raised $14.5 million in its first round of financing and plans to begin human trials of the MS vaccine in early 2004. If all goes well, a vaccine could reach patients in about seven years.

Once the technology is proved in humans, Bayhill plans to develop treatments for other autoimmune diseases. Indeed, the same basic approach has met with success in mouse models of rheumatoid arthritis and type 1 diabetes. New studies are testing whether it may even be possible to reverse existing joint damage. Vijay Kuchroo, a neurologist at Harvard Medical School, believes DNA vaccination "has broad applications" for autoimmune diseases. "I think it has a great future," he says. While that remains to be seen, the root causes of autoimmune diseases are in researchers' rifle sights. —*Erika Jonietz*



A mouse paralyzed by a variant of multiple sclerosis (top) walked again (bottom) thanks to a DNA-based vaccine aimed at errant immune cells.

COURTESY OF LAWRENCE STEINMAN

COMPUTERS THAT DO WINDOWS

ELECTRONICS | **Don't be surprised if your computer pulls a disappearing act one day. Research groups in the United States and Japan this year independently fabricated prototype transistors that are completely transparent. If the kinks can be worked out, the researchers say, the devices will change the way you think about computing. Transparent electronics could enable see-through displays—like video ads on store windows, or warning flashes on your windshield if a child darts in front of your car—and even invisible processors.**

The new transistors are made from oxide semiconductors, such as zinc oxide, which are currently used in conductive coatings for touch screens and windshield defrosters. Until now, oxide-based devices have not had good enough electrical properties—the ability to handle large currents, say—to make practical transistors. Recent advances have improved techniques for alternating layers of the oxide with other chemical layers on glass and plastic. The result: transparent transistors that switch electric currents on and off fast enough to make integrated circuits.

It will be years before these transistors compete with silicon on a large scale. But one application is only two years away: brighter and more efficient liquid-crystal displays, a $10 billion market. Most of today's laptop screens use opaque silicon transistors to control their pixels. The problem is that the silicon blocks much of the backlight, making screens dim and hard to read. Transparent electronics would yield brighter displays that use less power.

To make entire computers see-through will require faster and more stable transistors—and more efficient ways to pattern complex circuits. And see-through displays will require the development of transparent light-emitting devices. But eventually, says electrical engineer John Wager at Oregon State University, "anywhere there's glass, there can be electronics." —*Gregory T. Huang*

Leaders in Transparent Transistors

INSTITUTION	LOCATION	TECHNOLOGY
Oregon State University	Corvallis, OR	Transparent electronics on glass
DuPont	Wilmington, DE	Transparent electronics for plastic displays
Tohoku University	Sendai, Japan	High-speed transparent transistors
Tokyo Institute of Technology	Yokohama, Japan	World's fastest transparent transistors

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KILL THE OPERATING SYSTEM!

You use Windows, I use a Mac, and we both know people who use GNU/Linux. But for all the differences between these three families of computer operating systems, they implement the same fundamental design; all are equally powerful, and equally limiting.

Virtually every operating system in use today is based on a single computer system architecture developed in the 1960s and '70s. This architecture divides code running on computers into a "kernel," responsible for controlling the computer's hardware, and so-called application programs, which are loaded into the computer's memory to perform individual tasks. Applications, in turn, operate on named files arranged in a tree of folders. True, there are a few niche operating systems that don't adhere to this tripartite structure, but they are but bit players on the digital stage. Even PalmOS has a kernel, apps, and files (which PalmOS mistakenly calls "databases"). It's almost inconceivable that this approach won't be the dominant paradigm for many years to come. And that's a deep problem for the future of computing.

Hollywood, though, has a better idea. When computers show up in good science fiction movies, they rarely have interfaces with windows, icons, applications, and files. Instead, Hollywood's systems let people rapidly navigate through a sea of information and quickly address their needs. Some technical folks scoff at this representation as unrealistic. But why is that so?

Computing's standard model owes its success to the economics of the computer industry. The first computer programs were monolithic systems that talked to the hardware, communicated with users, and got the job done. But soon it became clear that organizations were spending far more money on software, custom software development, and training then they would ever spend on hardware alone. These businesses wanted guarantees that the programs they were creating would run on next year's computer. The only way to assure this was to take all of the hardware-specific code and put it into some kind of "supervisor" program—what we now call the kernel. The supervisor evolved into a kind of traffic cop that could allow multiple programs to run on the same computer at the same time without interfering with one another. That was vital back in the day when a single computer might have dozens of simultaneous users. It's equally important today for people who run dozens of programs simultaneously on their desktop systems.

But you could imagine building computers differently. Movie directors have pointed the way, showing interfaces that appear to make all of the computer's data and power always instantly available. Achieving such flexibility, however, would require us to rethink operating-system dogma. For example, instead of isolating applications from each other—where transferring data between them requires cutting, pasting, and usually reformatting—a hypothetical computer might run all programs at the same time and in the same workspace. Programs might not display information in their own distinct windows, the way they do now; instead, they would work behind the scenes, contributing as needed to a common display.

Most people can't imagine how such a system would work. The idea of editing an Adobe Illustrator document with Microsoft Word seems nonsensical: one program is designed for drawings, the other for words—and besides, they're made by different companies! Yet many Illustrator documents contain blocks of text: why not use Word's superior text-editing capabilities? In our imagined new computer, the boundaries between applications would melt away.

Computer scientists periodically experiment with systems that do away with the software barriers on which today's computers are based, but these systems are rarely successful in the marketplace. Both the Lisp Machine and the Canon Cat encouraged developers to create programs that ran in the same workspace, rather than dividing the computer up into different applications. The Apple Newton stored information not in files but in "soups"—little object-oriented databases that could be accessed by many different programs, even at the same time. The commercial failure of these systems does not vindicate today's way of computing but rather is testimony to just how dangerous the dominant-paradigm trap actually is.

For all their apparent differences, the three great families of computer operating systems—Windows, MacOS, and GNU/Linux—are all equally limiting. But Hollywood has a better idea.

Consider files and directories. The hierarchical directory system used by Windows, MacOS, and Unix made sense to computer pioneers who grew up using paper and filing cabinets. But why limit today's computers with 40-year-old metaphors? Computers have fantastic search capabilities. Some documents logically belong in multiple places; why not eliminate the folders and store all of the computer's information in one massive data warehouse? That's the way computers in the movies seem to work.

It's not such a far-fetched notion. It wouldn't take much to enable today's computers to store every version of every document they have ever been used to modify: most people perform fewer than a million keystrokes and mouse clicks each day; a paltry four gigabytes could hold a decade's worth of typing and revisions if we stored those keystrokes directly, rather than using the inefficient Microsoft Word document format. Alas, the convenient abstractions of directories and files make it difficult for designers to create something different.With a little thought, though, we could do far better. Hollywood has dreamed it; now Silicon Valley needs to make it real.

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Aged jet: A 747 jumbo jet, whose design changed the game three decades ago, nears completion in Boeing's Everett, WA, factory.

BOEING'S FLIGHT FOR SURVIVAL

The slump in commercial air travel has left Boeing's factory partly empty. A proposed superefficient jet, the 7E7 Dreamliner, might be Boeing's best bet to preserve its market dominance and to revive air travel.

BY DAVID TALBOT • PHOTOGRAPHS BY SIAN KENNEDY

Dreaming of Airborne Efficiency

Boeing says the 7E7 Dreamliner would be 20 percent more fuel efficient than comparable jets. Of this gain, half would come from next-generation engines, the rest from lighter-weight composite materials, efficient electrified systems, and tweaked aerodynamics.

MORE COMPOSITES
The majority of the jet's structure will be of composite materials, including wing structures. Boeing's most recent jet, the 777, is just 11 percent composite.

ADVANCED SYSTEMS
Simpler and more sophisticated electrical systems, and removal of some heavy pneumatic systems, will save 4,500 kilograms and improve fuel efficiency.

STRUCTURAL-HEALTH SENSORS
The 7E7 will likely include a network of advanced sensors that detect and report structural problems like tiny cracks, saving on inspection costs.

BETTER AERODYNAMICS
Advances in computer modeling of air flows and turbulence have enabled shape changes that reduce drag by 3 percent.

By almost any standard, Boeing's commercial-jet factory in Everett, WA, is an impressive place. For one thing, it is the world's most voluminous building—you could fit all of Disneyland plus five hectares of parking in it. And it's the birthplace of many of the world's largest commercial jets, including Boeing's 767, 777, and 747, the legendary 400-plus seat jumbo jet that has dominated much of long-distance air travel over the last three decades. One of the factory's football-field-sized doors is emblazoned with a giant image of three jets soaring toward a crimson sunset and the inscription "Building the Future of Flight Together." But on a recent drizzly day, the door was partly opened, revealing that the cavernous hangar, big enough to hold three mid-sized passenger jets, is empty.

Given the slowdown in the commercial-aviation business, the idleness of some sections of the huge aircraft factory is no surprise. But despite the economic doldrums, in an office park just a kilometer away, Boeing engineers are busily designing what they hope will solidify the company's future as a commercial-jet maker. It's called the 7E7 Dreamliner, and if all goes to plan, it will be Boeing's first newly designed commercial jet since the 777 was rolled out in 1995.

At first glance, the 7E7 will be a rather conventional-looking mid-size plane that carries between 200 and 250 passengers. But Boeing says it will burn 20 percent less fuel than today's similarly sized commercial jets.

What's more, built of lightweight composites and packed with sophisticated electronic controls and diagnostics, the 7E7 could cheaply and efficiently travel an ocean-hopping 14,800 kilometers, demonstrating the same range and speed as large jets, like the 747. In other words, the 7E7 could get you from Paris to Minneapolis without a stop and, company officials say, do it less expensively than any large commercial jet flying today.

Those numbers could have dramatic implications for air travelers. Relatively small, long-range planes could offer routine flights to far-flung international cities without stops in large hubs. Indeed, Boeing foresees a market for as many as 400 new direct routes between city pairs like Munich and Singapore, Dubai and Taipei, or Athens and Atlanta. Low operating costs and increased scheduling flexibility could help keep ticket prices down and provide a desperately needed boost to the ailing airline industry. In short, Boeing's engineers and designers are betting the 7E7 is the right plane for the struggling, highly competitive air travel business.

Whether the company's management agrees, however, remains to be seen. Weighing the need to replenish its

Sonic bust: Finding scant airline interest, Boeing killed the fast, sleek Sonic Cruiser.

ARTIST RENDERING COURTESY OF BOEING (SONIC BUST); INFORMATION GRAPHIC BY JOHN MACNEILL (DREAMING)

aging fleet of commercial jets against the daunting requirement of a multibillion-dollar investment to develop the 7E7, the company's board of directors is expected to decide whether to go forward in early 2004. If it approves the project—and that remains a huge if—the first planes would be delivered in 2008; if it doesn't, Boeing's engineers will have to go back to the drawing board, with the company's future in the balance. (Boeing is also doing a concept study on a next-generation 747, which would be 5 percent more efficient and slightly larger than the most recent 747s, which rolled out in 1989.)

Indeed, the stakes on the 7E7 could hardly be higher. Industry experts calculate it costs roughly $10 billion to produce a new model of commercial jet. And they estimate the 7E7 program is already consuming half of Boeing's annual commercial-jet research-and-development budget of $768 million. By Boeing's own admission, the fate of its entire commercial-jet business might well rest on getting the new plane right. "It's the future. It really is. It's a huge deal for us," says Mark Jenks, Boeing's director of technology integration for the 7E7 program. "If we get it wrong, it's the end. And everyone here knows that."

Aborted Takeoffs

On a metal stand in a hallway near the offices of the engineers leading the 7E7 project is a mockup of the recently shelved Sonic Cruiser. The Sonic Cruiser was to be an airborne luxury liner that promised both long range and near Mach speed—shaving two hours off a nonstop New York to Hong Kong flight and setting a new standard for fast international travel. Barely a year ago, the Sonic Cruiser's sleek, distinctive design alone was enough to spark renewed enthusiasm for the future of commercial aviation. But early this year, after finding little interest from ailing airlines, Boeing killed the program and shifted the bulk of its technology development efforts toward the 7E7. This wasn't the first time Boeing had got cold feet, either. Before the Sonic Cruiser came the 747X—a 747 variant with a longer fuselage and larger capacity that was killed in 2000; in the late 1980s, Boeing nixed a proposed

The Jumbo Bus

By deciding to build the superjumbo, double-deck A380—which will be the world's largest passenger jet when it debuts in 2006—Airbus is making a radically different design bet than Boeing is with the 7E7. Airbus, co-owned by two leading European aerospace companies and based in Toulouse, France, is banking that as airlines attempt to optimize their flight schedules in coming decades, more people will have to fly through centralized hubs like London, Tokyo, and Chicago. Simply put, the A380 will cheaply move huge throngs of people in and out of such hubs.

If Boeing's 7E7 represents a gamble that passengers will want more nonstop long-haul flights between a wide range of cities, then the A380 is a wager that air congestion at centralized hubs is going to get even worse, putting more pressure on airlines to find ways to increase passenger capacity. "The most efficient way—and the way the largest numbers of people will move in the future—is hub to hub," says David Venz, an Airbus vice president for external communications. "That is why we are building the A380."

There's logic behind both strategies, says Cynthia Barnhart, codirector of the Center for Transportation and Logistics at MIT. While efficient, mid-size planes could give passengers more choices in air routes, large jumbo jets like the A380 transport more people with fewer planes, reducing airborne congestion. The A380 program, says Barnhart, "is recognizing there's a worldwide issue with respect to limited airport and air space capacity."

What is certain is that the A380 is huge, and it directly challenges the market dominance of the Boeing 747. With a normal seating configuration, the A380 will accommodate 555 passengers (compared to the 747's 416); an all-economy A380 could pack 840 passengers (compared to the 747's maximum of 524 in a two-class configuration). And Airbus claims the A380 will be 15 percent cheaper to operate per seat than its rival.

Making a plane as large as the A380 fit into existing airports is tricky. At typical terminals, the plane's 80-meter wingspan squeezes in with just a half-meter to spare. Because the outer pair of wing-mounted engines hang over the edges of some airports' runways, those airports will need to move adjacent equipment to make room. The plane is so heavy that it must deploy landing gear with a total of 20 tires to distribute its weight without damaging runways. In fact, the A380 is so big that its parts now under construction in Germany, the United Kingdom, France, and Spain will require specially designed ships and barges to transport them to the final assembly plant in Toulouse.

Despite the plane's size, Airbus says passengers will be able to board and exit it as quickly as they could a conventional aircraft. If airports so choose, they can build Jetways with double-deck boarding to speed things up further. They might want to get started. With 116 orders already logged, the first A380s, which more or less resemble an overgrown London bus with wings, are getting ready to take off.

ARTIST RENDERING COURTESY OF AIRBUS

I want

employees
to have access
at work, at home
and on the road
without dealing
with three
separate providers.

I want

to e-mail
and make
local and
long distance
calls without
paying three
separate bills.

Not available in all areas.

150-passenger jet called the 7J7 that was intended to be more fuel efficient than its competitors, thanks to a new propeller design that could yield jetlike speeds.

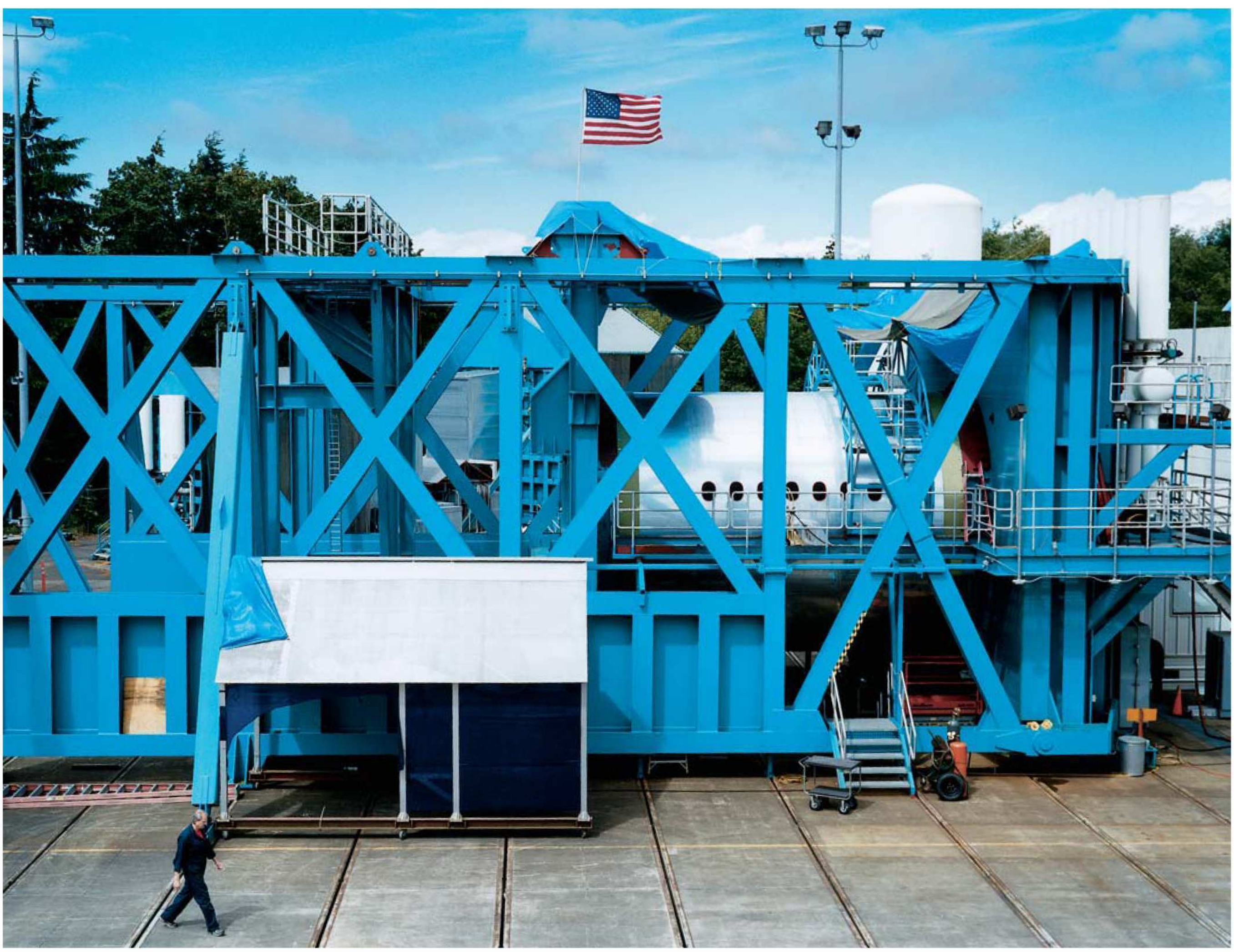
Such aborted takeoffs are beginning to threaten Boeing's marketplace prominence. While Boeing is still the largest maker of military aircraft in the world and in 2002 still made about 60 percent of the world's large passenger jets, its market share on the commercial side of the business has slipped dramatically in recent years. Airbus, the European consortium of aerospace manufacturers, which had just 19 percent of the market a decade ago, commanded 40 percent in 2002 *(see "Hitting Market Turbulence," p. 44)* and is closing the gap even further in 2003.

Indeed, this year Airbus expects for the first time to deliver more commercial jets than Boeing. The Toulouse, France-based company has more than 1,500 orders on the books, compared to Boeing's 1,100. Perhaps most ominously, Boeing's monopoly of the jumbo-jet market is about to end. The iconic Boeing 747 is still the world's only civilian jumbo jet, but Airbus will soon be challenging it with the 555-seat A380—the world's largest passenger jet—which the company says is more efficient than the 747 and will roll off assembly lines in 2006 *(see "Jumbo Bus," p. 37)*.

If Boeing cancels the 7E7, it will be left with no viable plans for an all-new plane that could sustain its dominance. Indeed, without a strong addition to its current fleet, Boeing's market share will spiral downward to 30 percent by 2013, predicts Richard Aboulafia, an aviation industry analyst at the Teal Group, a Washington, DC-based consultancy. The company "could coast on existing products for 20 years or more, watching market share decline," says Aboulafia. But "not having new products would begin to cripple the company after 2010, because their competitors would eat them alive with their new products."

Saving Billions

If Boeing's Sonic Cruiser was meant to be the Lamborghini of commercial jets, the 7E7 is more like the Honda Civic. Its key selling points are fuel efficiency and low operating costs. For Boeing's engineers, that means reducing manufacturing and maintenance requirements, as well as fuel use, by whittling weight and deploying technological tricks—such as more adaptable software systems and sensors that automatically and cheaply detect structural problems. The 7E7's 20 percent fuel efficiency boost will come from a combination of new technologies. Almost half will result from the introduction of next-generation jet



Crunch time: A prototype section of fuselage sits in a test structure behind Boeing's factory in Everett, WA. Made from a design that eliminates 9,700 connecting parts, the section will be subjected to twisting, shearing, and other forces simulating hard landings and bad turbulence.

engines supplied by players like General Electric, Pratt and Whitney, or Rolls Royce, according to Boeing engineers.

But the other half will come from weight reductions stemming from more widespread use of composite materials, more efficient and lightweight electrical systems that will partially replace bulkier pneumatic ones, and from a tweaked aerodynamic shape that reduces drag.

The last Boeing-designed passenger jet, the 777, used some composites. But Boeing says the 7E7 will be the first commercial aircraft the majority of whose main structure, including its fuselage and wings, will be made of these lightweight, superstrong blends of carbon fibers and epoxy. Composites are about 20 percent lighter than standard aluminum alloys and are more amenable to precise shaping (which reduces the total number of parts and saves manufacturing costs). And though composites generally cost 10 to 100 times more than aluminum to produce, Boeing and its suppliers say they have developed proprietary manufacturing technology that could dramatically narrow that gap. Boeing estimates the increased use of composites will alone account for as much as a 3 percent fuel efficiency boost.

Designers expect to lower operating costs even further through improved automated maintenance systems—in particular, advanced structural-health diagnostics. The disaster that befell an Aloha Airlines Boeing 737 in 1988 is a grisly tale familiar to everyone in the commercial-jet business. Tiny cracks that had formed around aluminum rivets resulted in a chunk of fuselage tearing off at 7,200 meters near the coast of Hawaii, sweeping a flight attendant to her death.

After the tragedy, regular checks of commercial aircraft for signs of structural damage were intensified, increasing safety but adding costly, time-consuming trips to the shop. Inspection methods include pouring colored penetrating fluid over the fuselage to reveal any hairline cracks, and exposing the fuselage to sound waves that send vibrations through its skin (the pattern of reflected vibrations indicates if cracks are present). While effective, such inspections can easily add millions of dollars to maintenance costs over the life of a plane.

Under pressure: As part of Boeing's effort to use more lightweight composite materials, a prototype wing structure is wired with strain gauges (left), then compressed until it cracks (right).

Simple strength: New software helped create a design with fewer small parts in places like the junctures of structural aluminum ribs and skin, for lower-cost manufacturing and maintenance.

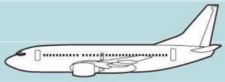
COURTESY OF BOEING (UNDER PRESSURE)

How the 7E7 Stacks Up

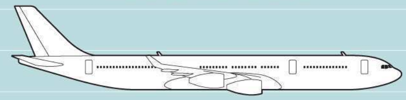
As a 200- to 250-passenger plane with ocean-hopping range, the 7E7 might enable new direct service between international city pairs like Atlanta and Athens. It would be roughly the size of the Boeing 767, but its range would compete with the 747's or Airbus A380's.

TYPICAL CONFIGURATION

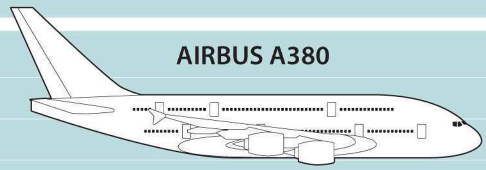
BOEING 737-700			AIRBUS A320
126	PASSENGERS	150	
33.6	LENGTH (M)	37.6	
6,200	RANGE (KM)	4,800	
38,200	WEIGHT (KG)	42,000	



BOEING 767-300 ER			AIRBUS A340-200
218	PASSENGERS	240	
55	LENGTH (M)	59	
11,300	RANGE (KM)	14,800	
90,800	WEIGHT (KG)	129,500	



BOEING 747-400 ER			AIRBUS A380
416	PASSENGERS	555	
70.6	LENGTH (M)	73	
14,200	RANGE (KM)	14,800	
184,800	WEIGHT (KG)	277,000	



To lessen the need for these inspections, Boeing says, the 7E7 will likely be riddled with advanced, networked sensors that automatically and continuously monitor structural health. Already, diagnostic sensors are standard equipment on jet engines *(see "If It Ain't Broke, Fix It," TR September 2001)*, where they monitor parameters like temperature, pressure, and emissions. And structural sensors are used in some military jets, where installation cost isn't as much of an obstacle. But now, "The technology is just starting to come along to the point where we can have monitoring technology on the structure of a commercial jet," says Jenks, the 7E7 technology integration director.

While Boeing won't discuss the specific kind of sensors it plans to deploy, recent academic and industry research suggests several possibilities. In one leading approach, a patch of ceramic material affixed to the interior of an aircraft's skin contracts and expands rapidly, sending out vibrations; a sensor detects the wave pattern that reflects back. New cracks provide new reflection points that show up as changes in this pattern. Whatever type of sensors Boeing chooses, their data will be analyzed by software and warnings of potential problems relayed to pilots and ground crews.

Boeing engineers are also rethinking the entire electrical network of the 7E7, hoping to cut back on the maze of wiring found in commercial aircraft. Onboard computing systems are getting simpler and more integrated, requiring less wiring. And wireless technology will play a role, too, in nonessential electronics like flight attendant call buttons. Whereas the similarly sized 767 has 160 kilometers of wiring, the 7E7 would have only 100 kilometers.

The resulting weight savings is modest—equivalent to about eight adult passengers—but the overall benefits of a new electrical scheme are not. "In addition to saving the weight, it's that much less you have to design, install, and worry about later on," reducing costs over the life of the plane, Sinnett says.

Boeing's engineers also plan to take a high-tech, collaborative approach to the design of the plane. The objective is to manufacture the 7E7's parts in such precise shapes and with such pristine accuracy that many of them can literally snap together. "We call it our Lego airplane," jokes Frank Statkus, Boeing's vice president of technology and processes. The Internet is key to achieving such precision. Boeing teams around the world—potentially at sites in Europe, Japan, Russia, and the U.S.—would codesign the 7E7. Despite their far-flung locations, they would all access the same file on a server. "The design lives in one place, where it used to live in 1,000 places," says Statkus. Eliminating the need to reconcile many versions of a design means fewer tiny errors when it's finished. What's more, the digital file containing the final design will be the same file used by suppliers to fabricate the parts. Previously, a supplier would sometimes "have to digitize our picture to tell his machine how to build it," Statkus says. "This translation sometimes caused errors."

Long term, the improved design process means a simpler digital catalogue for managing supply chains, as well as more efficient maintenance procedures for the airlines. And it could considerably simplify the process of designing future versions of the plane. All in all, the savings can be counted in the billions of dollars over the decades-long life of the plane design, for Boeing and the airlines that must maintain the planes, Statkus says.

Betting the Future

In some ways, designers of commercial jets have an impossible task. Though constrained by today's economic woes and technology limitations, they must think about what passengers

JOHN MACNEILL; SOURCES: BOEING AND AIRBUS

and airlines will need and want 50 years from now. After all, the first 747s were delivered in 1970, and new ones are still being built and are expected to last 30 years or more. That means the basic design of a commercial jet, if successful, can persist for upwards of 60 years. "It clearly outlasts all of us," says Walt Gillette, vice president of engineering and manufacturing for the 7E7. The need to plan for such longevity, he points out, makes designing a new aircraft like designing "a 100-story skyscraper."

Except no one has to keep building and selling the same model of skyscraper every year for 30 years. That's where the art of predicting the future comes in—an art that can clearly make or break a jet maker. Boeing essentially bet the company on the 747 in the late 1960s, a gamble that paid off with a world-dominating jumbo jet, a plane perfectly timed to the surging demand for long-haul, affordable air transportation.

But the industry has also seen some Edsel-like design failures and other miscalculations that have crippled entire companies. Lockheed Martin's L-1011, which made its first flight in 1970, was reliant on a single engine manufacturer, Rolls-Royce—a decision that proved financially disastrous when the then troubled engine maker imposed delays and price increases. Years later, the three-engine L-1011 proved more expensive to operate than newer, competing twin-jet designs, and this contributed greatly to Lockheed Martin's exiting the commercial-jet market in 1981. Once-powerful McDonnell Douglas failed to develop new models; Boeing bought the company in 1997 and quickly discontinued the MD-80, MD-90, and MD-11 commercial jets.

And then there was the Concorde supersonic-jet program, still the most radical technological gamble in commercial-air-travel history. It was essentially a government project, but even with substantial subsidies from British and French taxpayers, only 14 of the needle-nosed craft ever entered service. Today the surviving members of the fleet are being retired, with no supersonic commercial-jet replacements in anyone's sights.

Given such recent history, no one at the Boeing factory in Everett has to be reminded how critical it is to get the design of the 7E7 right—or what another market-dominant commercial jet would mean to the company. The sense of urgency around the Everett plant is almost palpable, extending well beyond the empty factory floor behind the hangar door marked "Building the Future of Flight Together."

Next to the office building where engineers are hashing out the 7E7 design, a sister structure owned by Boeing is vacant and available for lease. During a recent visit to an enormous

The Boeing 7E7 "is the future. It really is. It's a huge deal for us. If we get it wrong, it's the end. And everyone here knows that."

Boeing machine shop, the only sound other than echoing footsteps was a regular tapping noise—which turned out to be four workers playing Ping-Pong behind a screen of cardboard. It was, clearly, a facility just rearing to go on its next big project.

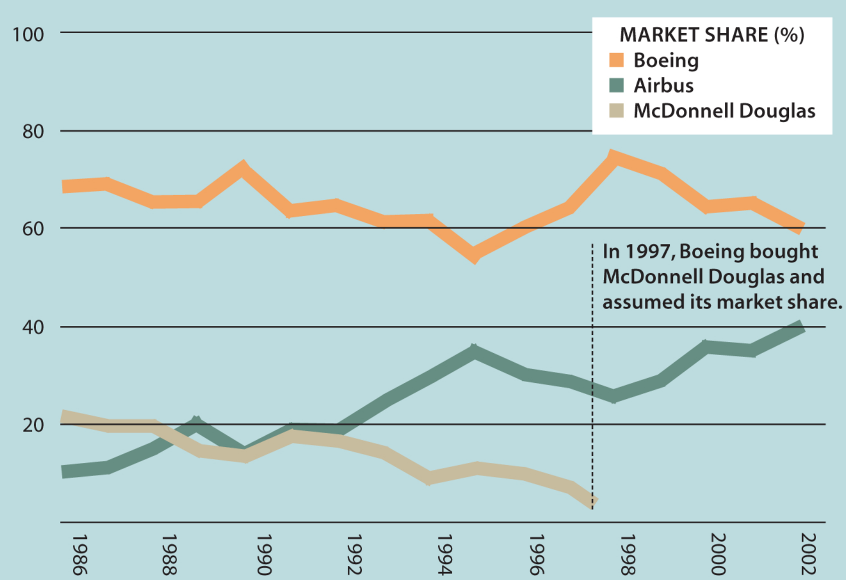
Gillette, for one, believes he has one more blockbuster plane left in him. He conveys some disappointment that it won't be the more radical Sonic Cruiser, which would have broken new ground in mainstream commercial air travel. "It was about the value of going fast," he says. "It's been 50 years since the industry really addressed the value of extra speed." But he also quickly acknowledges that the need to be bold must be balanced against economic realities—starting with what the airlines are willing to buy.

In short, the challenge for Boeing designers, says Gillette, is to use technology to make "the business case" for the new plane. Gillette knows it will all come down to whether his team can convey just the right balance of technological wizardry and manufacturing frugality to convince the board to bet the company one more time.

If Gillette and the other engineers at Boeing can win the day, they may well have helped determine how we will all fly for decades to come. And the sound of Ping-Pong balls in Boeing's cavernous machine shops may be replaced by the snapping together of the 7E7's parts, as they smoothly come together on a newly bustling manufacturing floor. TR

Hitting Market Turbulence

Boeing has traditionally been the dominant maker of large commercial jets. But Airbus rapidly closed the market share gap over the past decade, hitting 40 percent in 2002 and heading for an even stronger showing this year.



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LOST? HURT? BORN TO SHOP?

HARDWARE AND SOFTWARE THAT TRACK YOU INDOORS AND OUT MEAN YOU CAN BE BEAMED DIRECTIONS, RESCUED, AND SOLD TO, ANYWHERE, ANYTIME—OFFERING HIGH HOPES TO STRUGGLING WIRELESS CARRIERS.

BY ERIC W. PFEIFFER

WhereWare

Amanda sits idly at the bar of the trendiest restaurant in town, twirling a swizzle stick and sipping a cocktail. But cool as she looks, she's feeling anxious: her date is nearly 15 minutes late. She considers calling him but doesn't want to seem nervous or overeager. Still, she pulls out her cell phone, only instead of calling, she opens a special menu, enters his number, and sees that he is at the corner of Prospect and Broadway, not more than three minutes away. When he walks in, Amanda brushes off his apology, saying she wasn't at all worried.

Sound fanciful—or outright implausible? Lock on to location-based computing, the hottest thing in wireless, which offers new services to customers and new revenue streams to carriers, and could save lives in the process. The idea is to make cell phones, personal digital assistants, and even fashion accessories capable of tracking their owners' every movement—whether they're outdoors, working on the 60th floor, or shopping in a basement arcade. Already, Japanese telecommunications company KDDI offers over 100 different location-based services using technology developed by wireless-equipment maker Qualcomm, from bracelets to let parents track their kids in the park, to cell phones that point the way to cheap noodle shops in Tokyo's skyscraping Shinjyuku district. In Korea, two million citizens use their cell phones to locate nearby friends and, for example, find the most convenient coffee shops for impromptu meetings. In Europe, cell-phone networks can locate users and give them personalized directions to Big Ben, or the Eiffel Tower.

The U.S. is a bit behind the times: AT&T Wireless offers the hottest location-aware service, a friend finder, but only to a few hundred thousand of its 21.2 million subscribers. Market research firm Gartner, though, predicts that the number of American businesses and consumers using location-aware computing will skyrocket from 150,000 in 2002 to 42 million in 2005, with the market growing from $6 million to a whopping $828 million. Worldwide, Gartner estimates the market will exceed $26 billion by 2007. By then, or soon after, it's likely that devices will be able to locate people anywhere—at least outdoors—bringing the era of ubiquitous computing a giant step closer. In addition to helping stranded dates, shoppers, and hungry execs, location information could enable firefighters and other emergency personnel to find victims trapped in burning buildings. "Location-based services will become one of the fundamental services carriers will offer to their subscribers," says X. J. Wang, a senior analyst with the Boston-based research firm Yankee Group.

ILLUSTRATION BY JOHN CRAIG

Given what's expected, it's little wonder that companies from Qualcomm to Intel, along with a host of startups, have jumped into the location arena. But the operative word is "expected." Before location-based services can truly find their way, a number of obstacles must be overcome. The technologies have yet to achieve the accuracy and consistency needed to deliver the most advanced services—especially indoors, where walls and other obstructions impede signals. Standards need to be established for steering location information across diverse wireless networks, as well as for formatting data once it arrives at a cell phone or PDA. And privacy concerns are yet another potential stumbling block. Do consumers want even their friends to know their every move, let alone the folks at Starbucks? Or will users have the means to turn off location finding with the flip of switch?

Yet few in the field doubt that as the technology matures, such concerns will be dealt with. Consumers will then be left with a set of technologies working together to ensure that someone—or some network—always knows where you are, what you are looking for, and where you need to end up. Think of it as a permission-based Big Brother—an older sibling with a very good sense of direction.

IN THE FUTURE, SOME NETWORK WILL ALWAYS KNOW WHERE YOU ARE, WHAT YOU'RE LOOKING FOR, AND WHERE YOU NEED TO END UP.

YOU ARE HERE

Location-finding technologies have taken root in Europe and Asia *(see "Location's Rising Sun," p. 49)* due to the convenience they offer, but the driving force in the United States has so far been safety. Six years ago, the Federal Communications Commission mandated that cellular carriers be able to automatically locate anyone making an emergency 911 call. Carriers must be able to locate callers to an accuracy of 50 to 100 meters (depending on the technology used) by December 2005. "Hundreds of millions of cell phones have to have location awareness by law. That's a huge technology driver," says Larry Smarr, director of the California Institute for Telecommunications and Information Technology, which is helping develop, among other things, the next generation of wireless technologies.

At the moment, though, just which location-finding technologies will win roles in this FCC-mandated infrastructure is unclear. Each has advantages and disadvantages, which often revolve around accuracy—how closely it can pinpoint a person's location—power consumption, and price. Each offers its own solution to the problem of tracking users as they move outdoors and in—not to mention the up and down problem of finding someone on the fifth floor versus the 55th. The final infrastructure "will be a combination of a bunch of different things," says Jonathan Spinney, a manager at Redlands, CA-based ESRI, a leading mapping and positioning company.

The first phase of the challenge—and the part farthest along—is outdoor tracking. Two of the most promising means for outdoor tracking are the Global Positioning System and existing cellular networks. The U.S. Department of Defense launched GPS in 1978 to enable precision weapons delivery; today thousands of GPS-equipped cars help civilians navigate the traffic-clogged minefields of city streets. Receivers fix position by calculating the travel time of radio signals to at least three of the 24 GPS satellites circling Earth in known orbits. Brad Parkinson, an astronautical engineer at Stanford University, was the first director of the GPS program, back in 1972. "Even at that time, we had a sense it would be very large, particularly for civil applications," he says. "We also understood the location-based services that GPS enabled. But what turned out to be surprising is the accuracy we are now able to achieve."

That accuracy is now routinely within five to 20 meters, but because GPS requires a line of sight to the satellites, it doesn't

Finding Applications

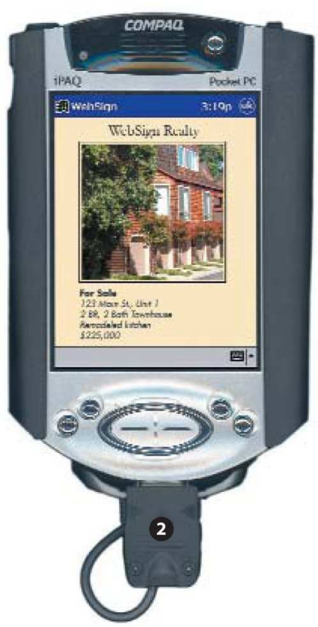
Technology firms and wireless carriers are racing to create services and applications that provide location-based information that customers will pay for. A few examples:

❶ Finnish company Ekahau makes software that can track users of Wi-Fi-enabled personal digital assistants and laptops through buildings such as shops or museums.

❷ Hewlett-Packard's "Websign" technology embeds Web pages in the landscape, enabling users to find information relevant to their locations.

❸ AT&T Wireless's "Find Friends" service allows customers to locate other AT&T subscribers in their areas.

❶



❷

❸

COURTESY OF EKAHAU; COURTESY OF HEWLETT-PACKARD; COURTESY OF AT&T

work well in the urban canyons of large cities. To get around this shortfall, some wireless carriers employ a technology known as assisted GPS. Here, the existing cellular network augments GPS receivers, which can take a few minutes to locate satellites. The network speeds up this search-and-find process and helps GPS work in areas where it might not otherwise, identifying the nearest positioning satellites and acting as a sort of "You Are Here" sign. Korean and Japanese carriers have widely adopted assisted GPS, and as a result, Qualcomm has sold millions of GPS-enabled cell phones to Asian customers. In a similar approach—call it "TV-enabled GPS"—Rosum, a Redwood City, CA, startup, is using powerful broadcast television signals, as opposed to cellular signals, to triangulate position. Broadcast signals could be preferable to cellular because they already cover a wide geographical area and penetrate buildings more easily. Rosum has joined with Sunnyvale, CA-based GPS leader Trimble to integrate its technology with GPS.

But any variety of GPS requires that consumers purchase compatible handsets, meaning it could take years to build up a critical mass, at least in the United States. So some wireless carriers have developed ingenious ways to use their existing networks alone to pinpoint customers' locations. Because wireless-phone networks are broken up into individual cells that hand off calls to each other, which cell a caller is using gives a rough indication of his or her location. The accuracy, however, is poor—a Gartner report puts it at between 30 and 150 kilometers, depending on conditions. If you are looking for a Chinese restaurant in New York, that's a lot of egg rolls to choose from.

A method called "time difference of arrival" can narrow things down. Similar to GPS triangulation, this approach plots location by measuring the exact time it takes for a signal from a cell phone to travel to three or more cellular base stations and calculating the differences. If only two cell sites are present, which is often the case in rural areas, then the angles of the arriving signals can provide the additional position information instead.

Unlike Asia, where the clear winner has been assisted GPS, the United States is seeing a hybrid approach: AT&T Wireless and Cingular, for instance, are using time difference of arrival, while Sprint and Verizon employ assisted GPS.

But while cellular location technologies don't require customers to buy new equipment, they still aren't as accurate as GPS—with resolutions of only about 120 meters, according to ESRI's Spinney. Although this is enough to meet government 911 mandates, it is not accurate enough to offer navigational services. Which is why Spinney believes that in the long run, assisted GPS will prevail globally. "Everything will go to assisted GPS," he says.

MOVING IN

Tracking users becomes much more challenging indoors, however. Assisted GPS can lose much of its accuracy due to ceilings, walls, and other obstructions, while cellular techniques don't even come close to making the grade: a 120-meter error range may let you spot a flashing restaurant sign down a city block, but even a five-meter miss in a skyscraper could put a user on a completely different floor. Although this isn't an issue in many applications, it could mean the difference between life and death to soldiers trying to identify friends and foes in an urban warfare setting or firefighters searching for victims in a blaze.

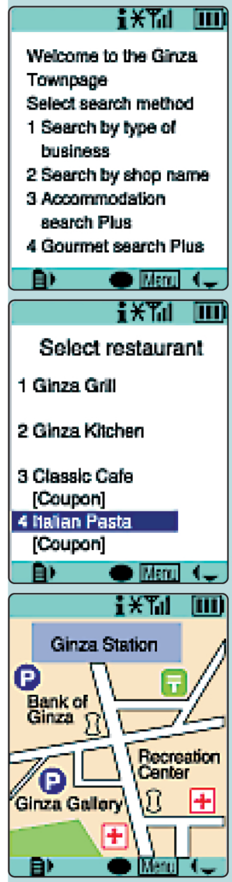
COURTESY OF NTT DOCOMO

Location's Rising Sun

Ren wants to meet his girlfriend at Z's, a bar in downtown Tokyo. She doesn't know where it is, so he downloads a color map to his cell phone and e-mails it to hers.

This has become a common scene in urban Japan since May 2000, when J-Phone, the country's third-largest wireless operator, launched J-Navi, Japan's first location-based service. Shortly after launch, J-Navi—which now gives directions to more than 15 million places of interest nationwide, including shops, cinemas, subway stations, and public toilets—was registering millions of page views. And it produced a veritable gravy train of revenue for J-Phone, a subsidiary of wireless conglomerate Vodafone, which charges subscribers for Web use as well as maps.

Japan's other two mobile-phone companies, KDDI and giant NTT DoCoMo, quickly followed with their versions of localized content, adding items like restaurant guides, weather forecasts, and train timetables. Dozens of other mobile-Internet services that exploit location information have sprung up since.



NTT DoCoMo offers location-based business searches, eatery guides, and maps.

"Carriers and their content providers alike have all enthusiastically adopted [location-based services]," says Daniel Scuka, business manager of *Wireless Watch Japan*. "Determining where a mobile user is has become a fundamental element of planning any new content, application, or service."

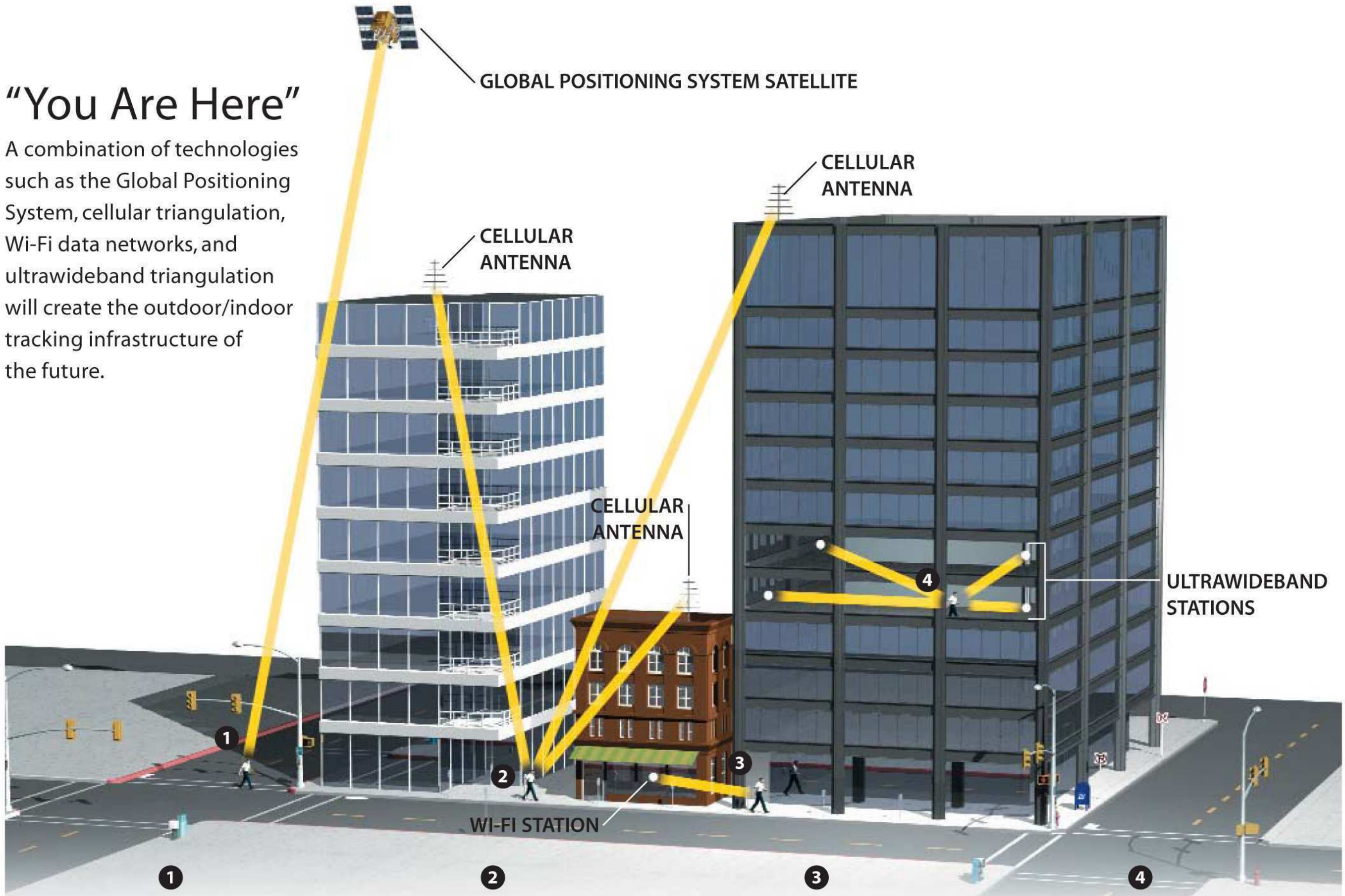
Actual numbers are hard to pin down, but estimates put regular users of Japan's location-based services in the tens of millions. Gadget-loving young Japanese like the services because they are cheap (in some cases free), easy to access, and convenient. The most-used services are maps, navigation, and area information—data on which restaurants and shops are nearby.

Location determination techniques range from no-tech to high-tech. In no-tech, phone users register their home locations, and providers send content to their phones—say, discount coupons to local video stores. High-tech employs the one-touch Global Positioning System handsets that carriers began selling last year, so that services can be tailored to a user's up-to-the-minute location. KDDI has sold about five million of the phones in their first year of availability.

For most purposes, however, low-tech triangulation using cell towers is accurate enough. Users can opt to receive marketing messages with coupons or promotional offers—the real gold of the mobile Internet—within certain areas. In March, J-Phone launched Loco Guide, which broadcasts a wide range of information to customers based on their current locations, including details on upcoming concerts, movies, and other events. In Japan, it seems, Big Brother is more interested in pitching you than watching you. —*Bob Johnstone*

"You Are Here"

A combination of technologies such as the Global Positioning System, cellular triangulation, Wi-Fi data networks, and ultrawideband triangulation will create the outdoor/indoor tracking infrastructure of the future.



	1 GLOBAL POSITIONING SYSTEM (outdoors)	2 CELLULAR TRIANGULATION (outdoors/indoors)	3 WI-FI NETWORKS (indoors)	4 ULTRAWIDEBAND (indoors)
Precision	Five to 20 meters	Down to 120 meters	One to 20 meters	Several centimeters
Companies	Trimble, Rosum, Qualcomm, Sprint, Verizon	AT&T Wireless, Cingular	Ekahau, Accenture, Symbol Technologies, Transat Technologies, UPS	Pulse-Link, Æther Wire and Location, U.S. military

JOHN MACNEILL

So what kind of technology could be used once a person steps inside and takes the elevator up, up, and away? One possibility is the popular wireless networking technology known as 802.11, or Wi-Fi. Numerous wireless carriers have begun installing Wi-Fi transceivers in hotels, cafés, and other commercial buildings to deliver high-speed Internet access to mobile users. This expanding infrastructure can also be used to locate people indoors, says Antti Korhonen, CEO of Helsinki, Finland-based Ekahau, which builds software that enables Wi-Fi location finding. This past spring, consulting firm Accenture used Ekahau's software in a pilot project for New York's Metropolitan Museum of Art: patrons wandering the Met's cavernous halls and stopping at a few of its two million works of art received information about the pieces in front of them with the click of a PDA button.

To achieve this virtual docent delivery, Accenture employees drew a detailed map of the exhibit area—a process that can take an hour for every 1,000 square meters covered, says Korhonen. Once the map was uploaded into a computer, employees walked around the museum, clicking on the map every three meters and recording the network's signal strength. Each location was matched to a specific signal strength, so that when museumgoers accessed the network, it knew where they were. With accuracy ranging from one meter to 20 meters, says Korhonen, Wi-Fi mapping is generally more precise than cellular triangulation. Big commercial applications will begin to emerge this year, he says; for instance, a German retail chain is using Wi-Fi in a pilot project to push information to shoppers depending on their location in a store. Since devices on the first floor of a building will measure significantly different signal strengths than those on other floors, Ekahau's technology can also solve the up-down problem, says Korhonen. "There is no way we could miss the floor," he says.

If location is calculated based solely on which Wi-Fi access point is closest, though, and not on painstakingly assembled signal-strength maps, the technology often places people on the wrong floors. And whether used indoors or out, a Wi-Fi transceiver covers a limited geographical area, with a radius of only about 90 meters. It's also susceptible to signal interference that can affect accuracy and is not particularly secure: nefarious characters might be able to determine your location based on your signal. According to Bill Yeager, a Sun Microsystems engineer working on location-aware computing, someone who knows that you are in a pizza place rather than at home could say, "Let's go over there and steal his home theater, or whatever they want to take."

It's not hard to imagine applications that will require greater accuracy, not to mention reliability and security. Luckily, another wireless technology could fill the gap: ultrawideband. Ultrawideband uses on/off energy bursts only billionths of a second long at extremely low power (one-

thousandth the power of a traditional cell phone) over a large frequency spectrum. These tiny bursts enable the technology to deliver data at speeds of hundreds of megabits a second, as well as provide ultraprecise positioning. And as with GPS or Wi-Fi, ultrawideband could be incorporated into a cell phone or PDA.

Distance can be determined by measuring how long it takes a pulse to travel between an ultrawideband transmitter and receiver, and position can be determined via triangulation if at least three signals are received. "If you have four locations, you can do vertical mapping," says Bruce Watkins, president and chief operating officer of Pulse-Link, a San Diego-based ultrawideband company. That enables the system to figure out how high an object is off the ground—or which floor of an office building or hotel a person is on. Because the technology—unlike Wi-Fi—relies on ultra-short pulses, the receiver can determine time of arrival in picoseconds, allowing it to establish location to within centimeters, according to Watkins. Yet because ultra-wideband is not as far along in its development and deployment as Wi-Fi, ESRI's Spinney, for one, sees it losing out on many applications, such as tracking consumers through malls or airports—where Wi-Fi systems are already being installed—and sending them promotional offers.

LOCATION DATA CAN HELP THE LOST, THE HUNGRY, OR THE STRANDED. BUT DO PEOPLE WANT THE FOLKS AT STARBUCKS TO KNOW THEIR EVERY MOVE?

THE PERFECT HAND-OFF

In an ideal world, a cell phone or PDA would seamlessly switch from, say, GPS to Wi-Fi when its user walked indoors, providing continuously updated location information. In the real world, though, the pieces still don't quite fit together. "We have a whole tool chest of location technologies, but what there isn't is a unified go-anywhere approach," says Smarr of the California Institute for Telecommunications.

Generally, the problem isn't technological: Wi-Fi and cellular radios, for example, can be integrated into a single device. Symbol Technologies, a Holtsville, NY, mobile-computing company, has developed a handheld for UPS that can access both types of networks. The difficulty lies in setting up service plans and contracts that will allow users to get location-based services as they move from outside to indoors. Cellular and Wi-Fi integrator Transat Technologies, in Southlake, TX, and Gemplus, a leading smart-card company based in Luxembourg, have begun to tackle the problem with special software embedded in smart cards. As carriers start to offer both Wi-Fi and cellular services, mobile users will be able to plug these cards into their cell phones and get access to both types of networks—and, presumably, all the location-based services they make possible.

In the shorter term, however, an even bigger problem looms: what if callers want to access location-based services using multiple cellular networks, say, AT&T Wireless and Sprint PCS, as opposed to a single carrier's combined Wi-Fi/cellular network? Software standards that will allow callers to use location-based services across the two main U.S. cellular technologies (which are known by the acronyms CDMA and TDMA) were expected to be ratified by this fall, according to Paul Hebert, a senior product manager at Redwood City, CA-based Openwave Systems, which sells location-based applications to carriers. Similar roaming standards for GSM, the world's other major wireless standard, could be approved next year, he says. The lingering question, though, is whether carriers will share their services with other companies' customers. "For location services, it is the business issues that need to be resolved," not technological ones, says Hebert.

COURTESY OF SUN MICROSYSTEMS

The Privacy Problem

Susan Landau is a senior staff engineer at Sun Microsystems Laboratories, which has launched a major project on location-aware computing. Landau, who researches privacy and security issues related to new technologies, addresses three questions.

TECHNOLOGY REVIEW: New technologies frequently raise privacy issues. Are there privacy concerns unique to location-based services?

SUSAN LANDAU: We've grown up with one model of the world, which is that you don't broadcast where you are. When you say, "I'm on my way home," nobody knows that you did a three-block detour to pick up flowers or mail a letter to somebody you weren't claiming to be in communication with. Is it impossible to live in an environment in which your cell phone and your PDA [personal digital assistant] give away your location? No. Is it an infringement of privacy? Of course. How will people react? The balance between privacy and convenience is different for everybody.

TR: Does broadcasting location also become a security problem?

LANDAU: Before September 11th, we saw it as a commercial privacy issue: did I really want to have the advertisement from the pizza joint flash onto my cell phone as I was passing? But now it's a very important security issue as well. This makes cell phones in some ways less useful to people. So one imagines, for example, that certain people should not be carrying cell phones, or at least should have their phones turned off. A congresswoman such as Nancy Pelosi is a good example; one would not want her to be broadcasting her location.

TR: So how do we deal with this?

LANDAU: Users should be in control at all times of giving out personally identifiable information—in this case, location. You want to include the capability to choose who can access your location information. You want the ability to give only limited access to the information to some individuals, maybe only certain hours of the day, or certain times of the week. For example, your boss might have access to your location information during working hours. Good privacy design might include requiring proofs of identity before location information is revealed. And you have to design the technology deciding what you want your privacy policies to be, what you want to enable. Because if you don't put those designs in at the beginning, then you may have locked yourself out of that capability.

On the assumption those business issues *can* be resolved, Intel is pushing to enable even greater interoperability across technologies. While the proposed standards would allow callers to use location-based services offered by different cellular networks, Intel's idea is to let them switch just as effortlessly between cellular, Wi-Fi, and ultrawideband networks. Intel's "location stack" system will also be able to compensate for the imprecisions of the various technologies to yield more exact position information, says Gaetano Borriello, director of Intel Research Seattle. "The reason we are pushing the stack model is to keep [location finding] independent of a specific technology," says Borriello. "We want to provide the infrastructure that will allow others to experiment and find those killer apps."

KILLER APPS?

Once the location-finding infrastructure and standards are in place, experts say, the U.S. market for location-based services will take off. Offerings will, no doubt, include friend and noodle finding, but a variety of other services are in trials or still on the drawing board. While everyone has a best guess as to what the real killer location application will be, they remain just that—guesses. "There are going to be things that just pop up," says Borriello.

At their core, the winning services will give people information that improves lives and saves time, or as ESRI's Spinney puts it, that "predicts the unpredictable"—enabling, for instance, easy navigation around traffic accidents or street closures. Because outdoor location-finding technology is more mature, services such as friend or restaurant finding have been offered first. But carriers see these as just the first wave of a variety of location-based services that "they can sell to drive revenue," says Arnold Gum, a Qualcomm senior product manager whose job is to figure out how new technology can help the world's wireless carriers make more money. In some cases, customers will be charged by how much data they consume: users of AT&T's friend finder service, for example, pay $2.99 a month plus usage charges, which depend on how many friends they ping. In other cases, consumers will be charged a set fee for each application.

So what other services would consumers, businesses, and even governments be willing to pay for? A PDA or cell phone that knew its location might display highly localized weather forecasts: "Severe thunderstorms south of the interstate by midafternoon." Minnetonka, MN-based Digital Cyclone is developing software that in the next few years will do just this, using GPS- and Internet-enabled mobile phones *(see "Pinpoint Weather,"* TR *June 2003)*. And if those severe thunderstorms happen to spawn high winds and lightning strikes, setting fire to a building, ultrawideband might help locate people trapped inside and track firefighters maneuvering to help them. "With this technology you'd know exactly where they are," says Pulse-Link's Watkins. He believes such a deployment is still a few years off, although the U.S. Department of Homeland Security is actively investigating using ultrawideband in emergency situations.

THERE'S A WHOLE TOOL CHEST OF LOCATION-FINDING TECHNOLOGIES, BUT STILL MISSING IS A UNIFIED APPROACH TO TRACK PEOPLE ANYWHERE.

The U.S. Defense Advanced Research Projects Agency also thinks enough of the technology that it has provided most of the $7 million funding for Æther Wire and Location of Nicasio, CA. CEO Patrick Houghton says his firm has built pager-sized demonstration devices that will locate soldiers—and anyone else—within a centimeter of accuracy over kilometers of distance.

Looking even further out, Salil Pradhan, a manager and senior scientist at Hewlett-Packard Labs, has developed "Websign," a technology that automatically delivers Web pages to cell phones or PDAs—but not just any Web pages. The links to these pages are "embedded" in the landscape itself. Take, for example, the popular Sunday excursion of house hunting. In Pradhan's world, your GPS-enabled cell phone would report your location within a certain city block. When you point the phone at a realtor's for-sale sign, up pops a detailed description of the home behind it. Walk through the front door and an indoor technology like Wi-Fi takes over, telling you all sorts of interesting things as you wander from room to room—say, who the agent is, the age of the roof, or when the kitchen was remodeled.

FUTURE DIRECTIONS

As our networks and devices get more adept at pinpointing our locations, a question naturally presents itself: are we sure we want them to? Location-based services could be a boon to consumers and carriers alike, but only if the pesky problem of privacy is addressed first. We don't want even our friends to know where we are at all times, let alone advertisers wanting to send us coupons. Sooner or later, and probably sooner, consumers will demand the ability *not* to be found. Even GPS coinventor Parkinson has concerns. "In five years, location-based services will become much more insidious than they already are. There's no doubt about it," he says.

Qualcomm's Gum understands the need for privacy and believes the best answer is giving consumers the ability to turn location finding off at their handsets, which Qualcomm's technology does. Similarly, AT&T's friend finder service offers users the option of being "invisible." In addition, the servers that deliver location services can be programmed with strict rules on who can find whom and when *(see "The Privacy Problem," p. 51)*.

In the long run, those in the field believe the advantages of location-aware computing far outweigh the disadvantages. "There is a lot of cool stuff you can do with location," says Gum. For one thing, he predicts, we will forget about road maps or directions and let technology worry about where we are. "I won't have to pay as much attention to street signs," he says. And in the future, he adds, our cell phones will even figure out when we are heading home and notify our home servers to turn on the lights. Within five years, agrees Spinney, location finding will become ubiquitous. "It is just going to be out there, and any application developer will be able to grab it and use it. Once that opens up, you have the potential for things to really explode." Then we may never be lost again. TR

REINVENTING THE TRANSISTOR

Molecules, not silicon, may be the workhorses of tomorrow's ultrafast, ultra-powerful computers. But even for Hewlett-Packard, home to one of the world's leading molecular-electronics labs, getting the technology to work is no easy feat.

By Claire Tristram

Every Friday afternoon at Hewlett-Packard Labs in Palo Alto, CA, R. Stanley Williams, one of the most respected thinkers in the field of molecular electronics, gets his group of 25 research scientists together to talk shop. One by one, they make their way to the conference room. Williams walks in exactly on time, sits down in front, and leans back, frowning, his hands steepled. He was hired by HP in 1995 to rethink the basics of computing and has handpicked the team inside this room to do just that. Williams likes to wear jeans, and his hair reaches halfway down his back, so he gives a first, fleeting impression of quietude and informality. But he apparently never smiles, and his people work 19-hour days to meet his deadlines. Williams waits a few minutes for the habitual latecomers, then stands up. He speaks in an efficient monotone.

PHOTOGRAPHS BY ANGELA WYANT

Sages of the small: Stan Williams (second from right) praises and prods his staff at a Friday all-hands meeting.

"We're going to hear first from Gun-Young today," he says. "What he has accomplished is magnificent. Everyone here owes him a lunch because his hard work has paid for our salaries for the last several months."

Gun-Young Jung, a recent postdoc from South Korea, stands up and quietly describes his work on nano imprint lithography, a process that uses a physical mold to create features as small as six nanometers across on silicon wafers. That's more than an order of magnitude smaller than the finest features achievable using today's advanced photolithographic processes. Sometimes things stick to the mold, though. It's like cake batter sticking to a pan, he says. His presentation lasts about ten minutes and is followed by two others.

Listening to these speakers, one after another, gradually conveys a sense of the group's style. They enjoy self-deprecating humor and inject frequent expressions of bewilderment into their scientific explanations, like "I don't know" and "it's still a mystery" and "I still need to investigate," and even "I am still quite a novice." And despite their obvious expertise, this isn't false modesty.

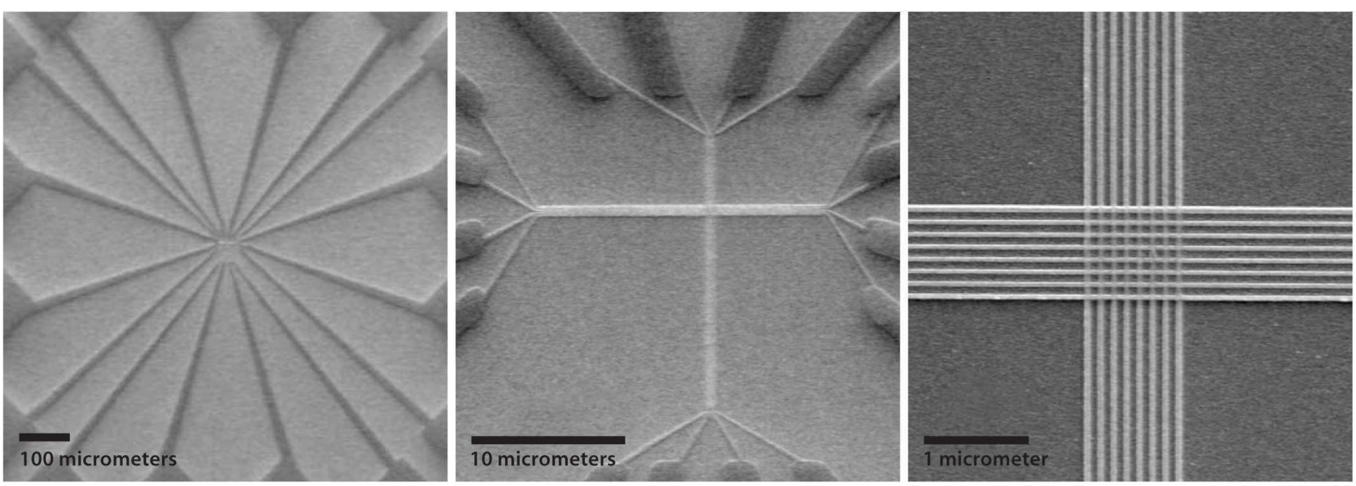
Williams's group faces a monumental task: trying to make computers whose functionality rests on the workings of molecules. To do so will mean reinventing the transistor. While silicon and other inorganic semiconductors have always been the basic building blocks of microchips, it turns out that organic molecules can also have some potentially useful electrical properties. Indeed, over the last few years, researchers have learned to synthesize molecules that can function as electronic switches, holding binary *1*s or *0*s in memory or taking part in logical operations. And molecules have one significant advantage: they are really small.

Such work is critical to the future of computing, because conventional chip fabrication technology is on a collision course with economics. Today's best computer chips have silicon features as small as 90 nanometers. But the smaller the features, the more expensive the optical equipment needed to manufacture them. A state-of-the-art fabrication plant for silicon microchips now costs some $3 billion to build. A chip in which silicon transistors are replaced with molecular devices, on the other hand, could in principle be fabricated through a simple chemical process as inexpensive as making photographic film. A circuit with 10 billion switches could eventually fit on a grain of salt; that's a thousand times the density of the transistors in today's best computers. A computer built from such circuits could search billions of documents or thousands of hours of video in seconds, conduct highly accurate simulations and predictions of weather and other physical phenomena, and do a much better job of imitating human intelligence, perhaps even communicating with us through natural conversation.

But no matter how tempting in theory, it's speculative, blue-sky research, and investing in molecular electronics is a gamble few companies have been willing to make. HP's confidence in Williams is a big reason it's one of the exceptions, says Shane Robison, the company's executive vice president and chief strategy and technology officer. "In addition to his ability to put together a first-class team of cross-disciplinary experts and an emphasis on how to turn science and technology into real products, Stan's best quality is probably his eternal optimism," says Robison. Of course, there's also the lure of immense profits, should Williams's technology ever displace conventional silicon chips. "Projects this ambitious are always a long shot, but we wouldn't be doing it if we didn't think there was a good chance of succeeding," Robison says.

A COMPUTER BUILT FROM MOLECULAR SWITCHES COULD SEARCH BILLIONS OF DOCUMENTS OR THOUSANDS OF HOURS OF VIDEO IN SECONDS.

To be sure, the company has hedged its bet by being cautious with funding. Williams's group has a four-year, $12.5 million grant from the U.S. Defense Advanced Research Projects Agency (DARPA), and HP provides matching funds, but about half of the DARPA funding goes to university research partners. Signs of economizing are everywhere in the lab, from a shortage of supplies in the coffee room to jury-rigged equipment. Nonetheless, the group has made one breakthrough after another—most notably, by proving that a "crossbar" design once common in conventional



COURTESY OF R. STANLEY WILLIAMS

Zeroing in: An electron microscope zooms in on HP's eight-by-eight nanowire grid. Molecules between the grid junctions act as switches.

Vanquishing glitches: Engineer Tan Ha demonstrates clean-room equipment used to create molecular-scale electronics.

electronics can be resurrected on the molecular scale. In a demonstration last year, the group trapped molecules in the junctions between titanium and platinum nanowires arranged in an eight-by-eight, one-micrometer-square grid, and showed that the molecules can be switched "on" and "off" at specific junctions—a first step in building a working memory or logic device.

Williams was first to come up with an architecture for molecular computing that "worked," says Meyya Meyyappan, director of nanotechnology research at NASA Ames Research Center at Moffett Field, CA. "I can't think of anyone else who has that kind of forward thinking." But despite these breakthroughs, the challenges in making molecular electronics are many and baffling. How do you make nanocomponents interact with the conventional electronics needed to get information in and out? How do you program a computer made from molecular electronics? But most fundamentally, what materials make the best molecular switches, and how can they be arranged with the precision and reliability required for mass manufacturing?

That last question is one of the major concerns of Williams's lab these days. And as time spent with the researchers reveals, things at this scale are so difficult to observe and measure that conclusions can easily crumble back into speculation—as when seemingly important results turn out to be anomalies in experimental procedure or mistakes in interpretation. Even successful, verifiable results still present more questions than answers. When electrons travel through a macroscopic wire, they behave more or less like fluid in a pipe running downhill. But what happens when a billion or so electrons per second are passing through a single molecule?

To borrow a favorite phrase from those in Williams's group, it's a mystery.

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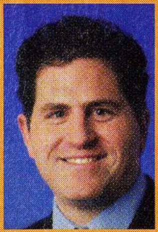
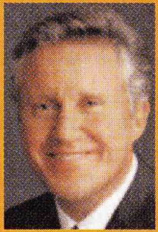
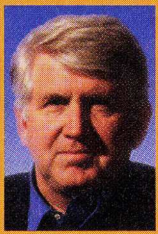


KEYNOTE
Michael Dell, Founder and CEO, Dell Computer Corporation

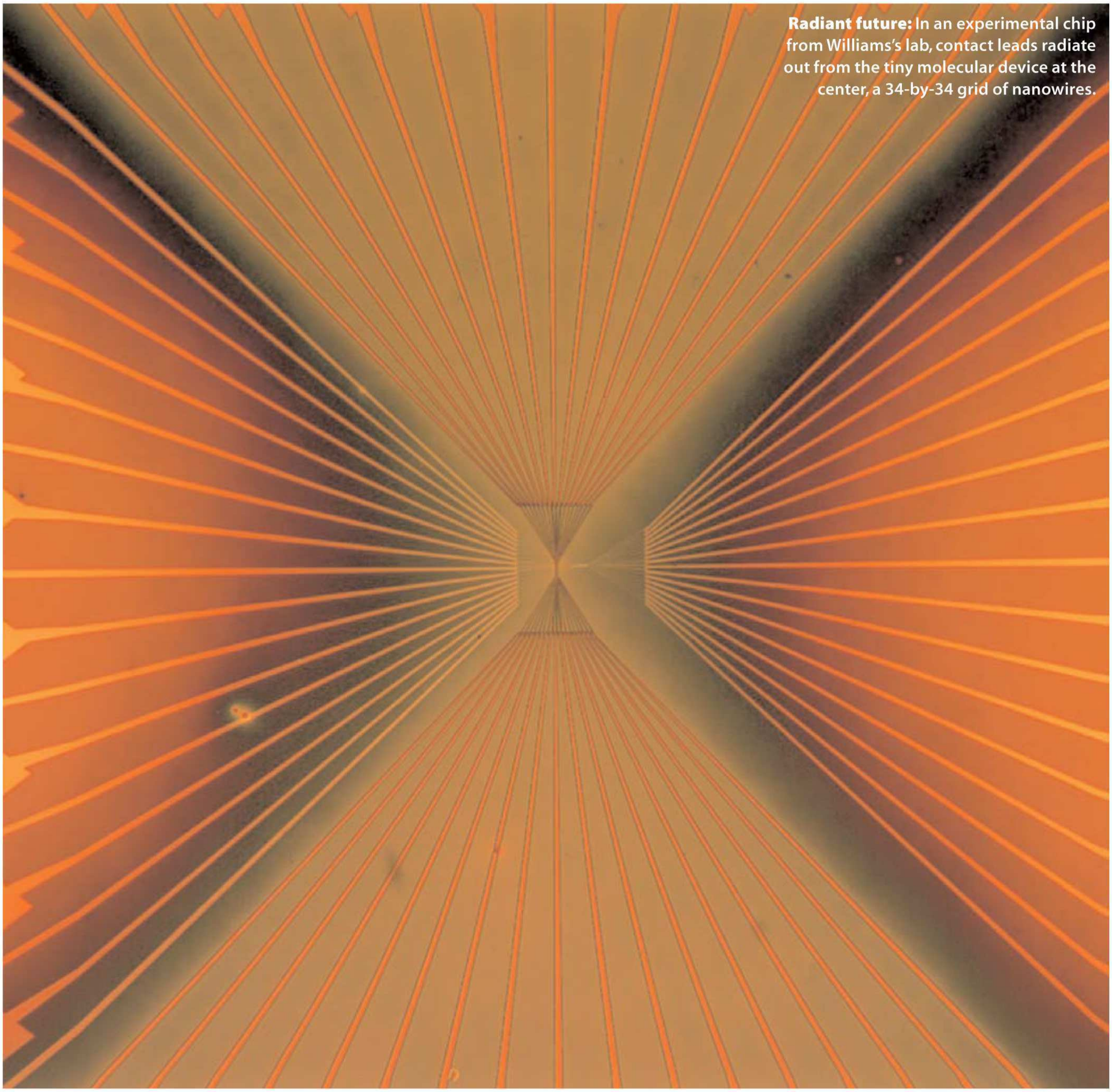
KEYNOTE
Nathan Myhrvold, Co-Founder and Managing Director, Intellectual Ventures



KEYNOTE
Jeffrey R. Immelt, CEO and Chairman, General Electric



TR100 HOST
Bob Metcalfe, Founder, 3Com Corporation, General Partner, Polaris Venture Partners



COURTESY OF HEWLETT-PACKARD LABS

It turns out that a little humility is a very good thing in this field, and serious researchers are reluctant to supply even rough predictions about when molecular electronics will meet the same rigorous standards of manufacture and testing that today's computers do.

"If you were to ask me when we'll start seeing these things commercialized, my answer is that I don't know," says Williams. "We don't understand the fundamental physics of why molecules switch. Until we do, we can't build a factory to produce them. It might take us decades to understand it. Or we might figure it out tomorrow."

WORKING BLIND

Spend some time in Williams's lab and you start to understand why a lot about molecular electronics is still a mystery, beginning with the relatively simple question of what exactly the researchers are building. Yong Chen, a native of China and a member of Williams's group since 1998, spends a lot of his time sitting in a stuffy, windowless, nine-square-meter room padded with thick foam. It's the home of a delicate electron microscope, which uses electron beams to create a rough picture of the structures Chen creates in the laboratory down the hall.

Chen is the leader of the team that has given the group its biggest public success to date, the 64-bit crossbar memory. His team first imprinted eight parallel nanowires made of titanium and platinum on a silicon substrate, and covered these wires with a one-molecule-thick layer of a synthetic chemical called rotaxane. They then deposited a second set of titanium wires perpendicular to the first, creating the possibility of an electrical connection between the wires at any junction in the grid.

Each molecule of rotaxane—which was invented by chemist Fraser Stoddart at the University of California, Los Ange-

les—consists of a long axle with two lumps of atoms at each end, and a ring of atoms circling the axle. Stoddart and Williams's groups theorize that when a voltage is applied through a specific, intersecting pair of nanowires, the rings on the rotaxane molecules between the wires "jump" from one end of the axle to the other and stay there until another voltage is applied. This could raise or lower the molecules' resistance to electrical current, and these two states of conductivity would represent digital *1*s or *0*s. Now Chen, eager to see how small he can make such a device, is trying to print the individual wires even closer together. It's painstaking labor, where you never know if you're making progress until the moment it works.

Today Chen is open mouthed, rapt, focusing absolute attention on the monitor in front of him, while also trying to carry on a conversation. He is not entirely successful. Several minutes pass quietly as a question hangs in the air, unanswered. He increases the microscope's magnification as he searches through a series of fuzzy, gray-on-gray images that look like satellite photos of a desert.

"After we finish the fabrication process, we come in here to check what kind of thing we have got," he says. "I want to see if the wire is grounded to the substrate or suspended above it. There's one. Oops, I lost it."

Eventually he finds something that looks like a length of rebar on a pile of charcoal dust but is actually a wire, 35 nanometers in width, resting on the silicon base. He takes a picture, silent again, holding his breath since sound waves will affect the quality of the image.

"We can talk now," he says. "Here, in fact, you can see this wire is broken. Too bad. This is a routine experiment, frankly." Chen's goal is to find a combination of materials—a "recipe," if you will—that will impart a Teflon-like nonstickiness to the mold that deposits the wires on the substrate; otherwise they bulge and twist when the mold is removed. But sitting in this hushed, foam-covered room, watching one of the leading scientists in the field searching through grainy images, you realize just how difficult it is to work on this scale. Three weeks later, after five months of painstaking experiment and observations, Chen and Gun-Young Jung find the result they were looking for, bringing the possibility of molecular-sized circuits a small step closer.

"I miscalculated several things," Chen says simply.

Now he can move on to the next problem.

SWITCHING PLACES

Observing results, of course, is the last step in a train of events that traditionally begins with a theory about how things should behave. In the case of molecular electronics, though, very little has run a straight course from theory to experiment to result. Theories can languish for years waiting for tools precise enough to test them. In fact, chemists first proposed the idea of molecular electronics in the mid-1970s, but another 20 years would pass before anyone could begin to put it into practice. Lately, though, experimental results have begun to leapfrog the ability of theorists to explain them.

One puzzle is the lack of consistency in measuring experimental results, from lab to lab and even from experiment to experiment. Alex Bratkovsky, a theoretical physicist and native of Moscow who joined HP in 1996, says he was one of the first to realize that a molecule's orientation between metal electrodes is critical to understanding its switching properties. "The current depends tremendously on how the molecule connects with the substrate," Bratkovsky says. "The signal may go away, then come back, depending on the position of the molecule. We disregarded that fact for quite a while." Since controlling the orientation of the molecule is still beyond current experimental tools, results vary widely from lab to lab, and scientists need to judge in many instances whether differences between their results have real meaning or can be explained by effects still outside of experimental control.

To understand the switching phenomenon, the HP researchers are studying a range of new molecules that might be controlled more easily than rotaxane, Bratkovsky says. Some of these are already being designed, but progress is slow. It can take more than two years to design, simulate, synthesize, and finally test a molecule for its electronic properties—after which researchers may find themselves beginning all over again.

Across the hallway from Bratkovsky, Duncan Stewart, an experimental physicist recently hired by Williams's lab, spent more than six months on a contrarian experiment to help investigate why some molecules can act as molecular switches, changing their conductivity in response to an applied voltage. Instead of designer molecules like rotaxane, Stewart used a simple hydrocarbon molecule consisting of a chain of 18 carbons surrounded by hydrogen atoms. Stewart calls it the "Plain Jane of the molecular world." It's stable, inert, and theoretically should have no interesting electronic properties. But it switched anyway.

"I have heaps of data, and the story is that the data do not fit any model, or any existing theory. So even in the simplest case, we don't understand how electrons are traveling through a molecule," he says. "At times it's extremely frustrating. You have to be very pigheaded, beat your head against a wall for six months, and eventually a single brick budges, and eventually the whole wall crumbles and you see another wall."

"YOU HAVE TO BEAT YOUR HEAD AGAINST A WALL FOR SIX MONTHS...AND EVENTUALLY THE WHOLE WALL CRUMBLES AND YOU SEE ANOTHER WALL."

THE DUST IN THE MACHINE

If the materials studied by these researchers seem baffling and unpredictable, the machinery they use is even more so. Progress in molecular electronics is often at the mercy of unpredictable glitches in the experimental equipment. This is, after all, laboratory science and not engineering.

Tan Ha, a native of Vietnam, is in charge of the equipment used in the lab's clean room. Two or three times a day he dons a clean-room suit and goes into the

room to test, adjust, and modify equipment for what are in many cases first-of-a-kind experiments. We suit up. "Now we're ready for chemical warfare," he says. The mask over his face makes it difficult to judge whether he is joking.

Once inside we make a beeline for a machine called a chemical vapor deposition reactor. It looks like a big steel cylinder on its side, encased in glass. "I have a special relationship with this machine," he says, and touches the glass with a gloved hand.

This type of reactor is standard fare in semiconductor fabrication facilities, but Ha has modified the machine to perform the ultraprecise experiments required by Ted Kamins, a member of Williams's group since 1995. Kamins has worked for years on the ultimate dream of nano research: making devices "grow" in desired structures rather than building them piece by piece. His goal is to grow the nanowires required by molecular electronics, as an alternative to using nano imprint lithography. So far, Kamins has synthesized wires as small as 10 nanometers in diameter by exposing "nanoparticles" of various materials to a mixture of gases in the deposition reactor. In the ensuing reaction, long chains of silicon grow up around the particles, producing what looks under the electron microscope like a forest of needles.

Growing the wires required for molecular electronics is exciting stuff, but Kamins's particular experiments almost didn't happen. Ha tells me that he spent over a year of his life trying to make the machine work. "Every time we ran an experiment, contamination would destroy the process," he says. It wasn't that the machine was broken; it's just that no one had ever needed to do the experiments that Kamins wanted to do. "It got to be a spiritual agenda for me," says Ha. "Ted was frustrated. So was I. I'd be in here on my knees all day long, modifying things screw by screw. I'd go to bed at night and close my eyes and see the plumbing diagram on my eyelids. It turned out to be a problem in the exhaust system. I went home and told my wife, 'That's it; I am a proven equipment engineer.' That's how happy I was."

PICKING A WINNER

Much to Duncan Stewart's disappointment, Williams asked him to publish his results with the hydrocarbon molecule after six months and concentrate on other work. Yet Williams encouraged Ha to keep working on his knees and dreaming about plumbing diagrams for a year, for experiments that Williams estimates are at least six years from fruition and may never yield a practical result. In a sea of competing theories and possibilities, and with the budget pressures he complains about with some regularity, how does he decide?

"It's a matter of experience," Williams says. "I've been down many blind alleys many times in my career. They're so enticing. You can get into these things and think, okay, just one more step, just one more step. Other things feel like they are in the right direction, and I can see where we're going." In other words, he has learned to trust his intuition, because it's all he has. "I've been through the cycle many times."

"STAN IS A SMART GUY, GOD BLESS HIM, AND IF ANYONE CAN SOLVE THESE THINGS, IT'S GOING TO BE HIS TEAM. BUT THEY HAVE A STEEP HILL TO CLIMB."

Williams's longest commitment to any idea in molecular electronics is to the crossbar architecture. But he admits that even this idea might be a blind alley. Will it ever be possible, for example, to cleanly trap molecules at the junction of two wires with complete confidence in their orientation? Then there's the practical problem of gain, or turning a weak electrical input into a strong output; this is a critical capability needed both to carry out logic operations and to amplify the tiny currents crossing the molecular switches so that conventional silicon systems can detect them. And it's a problem with no demonstrated solution.

"Stan is a smart guy, God bless him, and if anyone can solve these things, it's going to be his team," says James Tour, a Rice University chemist who is working on a competing approach to molecular computing. "But he's got a tough problem. At every crosspoint the molecules need to be stable. Then they need to interface with all the wires coming out. There's an enormous cost to that. They have a steep hill to climb."

"It's certainly possible that we are wrong," admits Williams. Then he shakes his head and stops being humble for a brief moment.

"I don't think so," he says. "I think we've picked the winner, something that will allow this thing we call Moore's Law to continue on for another 50 years. I used to think it was impossible. Now I think it's inevitable."

Alternatives to Silicon

TECHNOLOGY	COMPUTING ELEMENTS	LEADING INSTITUTIONS
DNA computing	DNA and RNA strands in solution	University of Southern California, Weizmann Institute of Science
Molecular electronic devices	Molecules such as rotaxane	Hewlett-Packard, Yale University
Nanocells	Gold nanoparticles deposited in random arrays	Rice University
Nanotube electronic components	Carbon nanotubes acting as transistors, memory, and wires	IBM, Harvard University, NASA Ames Research Center
Quantum computing	Quantum properties of electrons and molecules	MIT, IBM, Hewlett-Packard, National Institute of Standards and Technology

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ZKM Karlsruhe

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Isis Pharmaceuticals
Dr. Jennie Mather
Raven Biotechnologies, Inc.
Prof. Svante Paabo
Max-Planck-Institut fuer Evolutionaere Anthropologie
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Prof. Anthony G. Evans
Materials Department, University of California, Santa Barbara
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SEED Magazine
Mr. Robert Cringely
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SchoolNet Africa
Prof. Calestous Juma
Kennedy School of Government, Harvard University
Dr. Claudio Jose Marinho Lucio
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a sharper picture of health

FUZZY X-RAYS AND PAINFUL BIOPSIES ARE OFTEN THE ONLY WAY TO DIAGNOSE DEADLY DISEASES. BUT POWERFUL NEW IMAGING TECHNOLOGIES ARE BEGINNING TO REVEAL THE MOLECULAR SIGNATURES OF MANY OF THESE AILMENTS, OFFERING THE POSSIBILITY OF TESTS AND EVEN TREATMENTS THAT ARE FASTER, MORE ACCURATE, AND LESS INVASIVE.

NORTHWESTERN UNIVERSITY CHEMIST THOMAS J. MEADE MEANS NO DISRESPECT to his medical colleagues, but when he looks at the state of the art in diagnostics, he suggests that, for some procedures, physicians might as well use "stone knives." Take, for example, mammography. "You know going in that there's a one in five chance of a false positive or a false negative. You have an x-ray that's not even smart enough to differentiate a shadow cast by a calcium spot from a tumor. After reading the film and seeing a shadow, they do the prudent thing and stick a 16-gauge needle in you for a biopsy. Then you have to spend the next five days freaking out that you've got breast cancer until you get the results," he says.

Some of Meade's annoyance stems from the fact that his wife endured just such a false alarm—as will an estimated quarter to half of all women who undergo annual mammogram screening over the course of 10 years. But Meade's criticisms go well beyond the specific failings of mammography and breast biopsies; to him and a growing number of other medical researchers, today's diagnostic tools are too uncertain and invasive—just too primitive. Working at select academic centers and industrial

BY JOAN O'C. HAMILTON

Rethinking diagnosis: Northwestern University's Thomas J. Meade believes molecular-imaging tools will lessen uncertainty and anxiety for patients.
PHOTOGRAPH BY CHRIS LAKE

labs around the world, these researchers are developing a suite of new tools that will enable doctors to spot disease instantly and accurately, without ever taking a scalpel or biopsy needle to their patients' skin.

The new discipline is called "molecular imaging," and it is fundamentally altering physicians' ability to view the body and its processes. Most conventional imaging tools, from x-ray to magnetic-resonance imaging, provide anatomical or structural information: is there a lump in the breast or a shadow in the lung? Molecular imaging goes beyond anatomical information to reveal functional data—the cellular activities that characterize tumor growth or inflammation, for example.

This is important because cancer and other diseases often begin with subtle cellular changes, well before a structural abnormality, such as a tumor, is detectable. What's more, the new advanced imaging methods can help distinguish between diseases that look similar but actually involve different molecular malfunctions—and thus require different treatments. "Disease is being redefined in terms of its molecular signature," explains Daniel Sullivan, associate director of the National Cancer Institute and head of the institute's biomedical-imaging program. "In the future, people will talk about cancer by the molecular abnormality, not by the organ of origin."

And in the future, molecular imaging could be integral to every step of health care. Exquisitely sensitive periodic scans could flag any worrisome changes—the presence of a particular protein associated with the beginning of a cancer, for instance. Should doctors eventually spot a lesion, the imaging process itself would yield enough information about the biochemical malfunction not only to make the diagnosis without a biopsy, but also to help determine the best therapeutic option. Still more noninvasive imaging would closely track the treatment's progress and the course of the disease.

It might take 20 years or more for this complete picture to emerge. But the first generation of technologies to make it possible is already appearing. Thanks to advances in a range of disciplines, from molecular biology to optics to computation, researchers have begun to design chemicals that, once injected into the body, swarm to particular molecules associated with certain diseases and light them up, allowing physicians to easily spot problem areas.

FOR SOME CANCERS, ONLY 20 PERCENT OF PATIENTS RESPOND TO DRUGS, BUT 90 PERCENT HAVE SIDE EFFECTS. MOLECULAR IMAGING COULD SPARE PATIENTS PAIN AND WASTED TIME.

More than half a dozen such molecular-imaging agents are now on the market, most of them for cancer diagnosis; another handful are in clinical trials, and even more are in the development pipeline. Targets for these new diagnostic tools include not only cancers but cardiovascular disease and ills of the central nervous system. "All these technologies are growing incredibly rapidly," says Harvard Medical School radiologist Umar Mahmood, a principal investigator at Massachusetts General Hospital's Center for Molecular Imaging and Research. "We're not doing incremental work. These are leapfrog advances."

Indeed, it's a big enough jump forward that government, the established diagnostics industry, and a few venture capitalists are making substantial investments in the field. The National Cancer Institute has designated molecular imaging an "extraordinary opportunity," spending more than $100 million on it in recent years and asking for $78 million in 2004. To keep up, companies like General Electric—which already has a $9 billion business in conventional medical imaging machines and systems—are venturing further into molecular biology and chemistry and inking deals with major pharmaceutical companies and startups to develop new imaging agents *(see "A Snapshot of Molecular-Imaging Companies," this page)*. For the industry and patients alike, says Eric Stahre, general manager for genomics and molecular imaging at GE Medical, "molecular imaging has the potential to change the game."

The Next *Blockbusters*

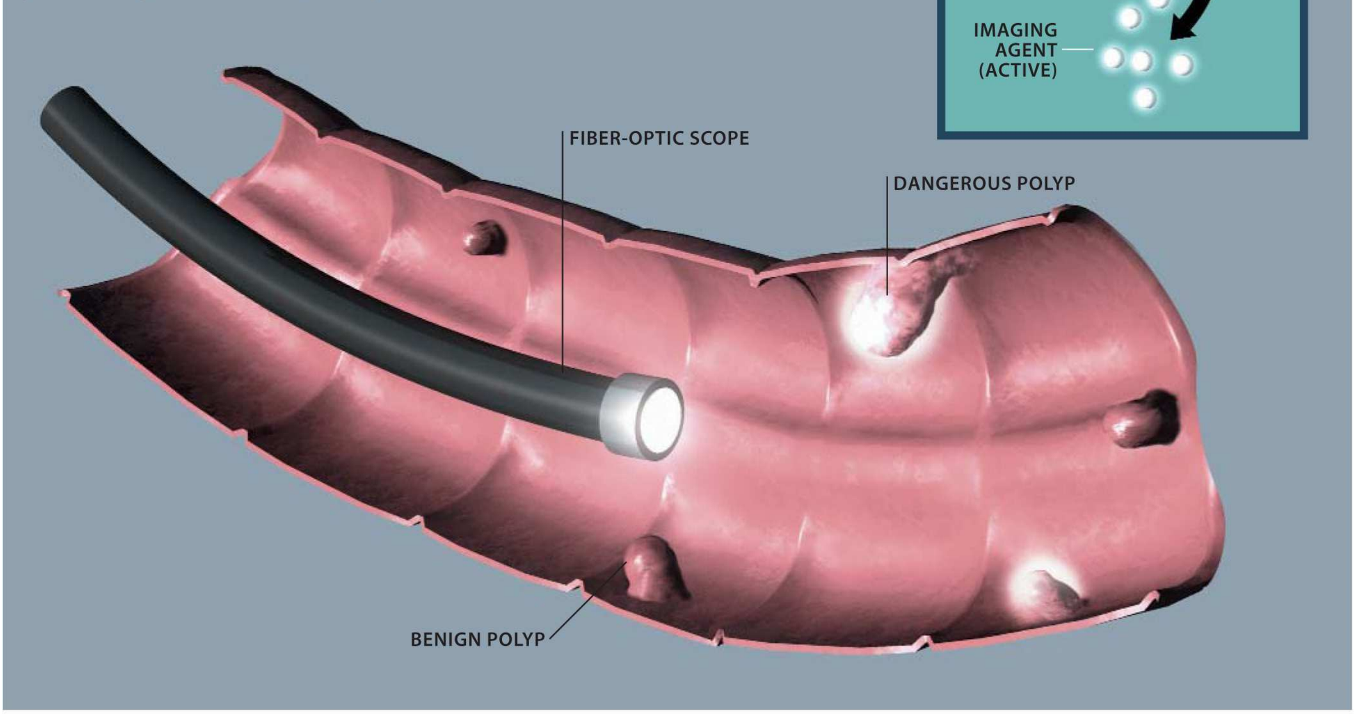
TAKE APOMATE, A MOLECULAR-IMAGING agent made by Boston, MA-based Theseus Imaging (a subsidiary of North American Scientific) that gives physicians a novel view of a biological drama that plays out in the body all the time. The complex chain of events that leads

A Snapshot of Molecular-Imaging Companies

COMPANY	PROJECT	PARTNERS
GE Medical Systems (Waukesha, WI)	Imaging instruments and agents	GlaxoSmithKline, Amersham Health
Kereos (St. Louis, MO)	Nanoparticle imaging agents for cancer and heart disease	Dow Chemical, Philips Medical Systems
MetaProbe (San Diego, CA)	Imaging probes for neurodegenerative, cardiovascular, and liver diseases	University of Wisconsin, Vanderbilt
Molecular Insight Pharmaceuticals (Cambridge, MA)	Imaging agents designed to identify heart damage	Harvard University, Syracuse University, Georgetown University
Theseus Imaging (Worcester, MA)	Imaging agents for cancer and heart disease	Philips Medical Systems
Xenogen (Alameda, CA)	Optical imaging in animal models of disease	AstraZeneca, Biogen, Bristol-Myers Squibb, Chiron, Eli Lilly, Millennium, Novartis, Pfizer

Molecular Colonoscopy

To distinguish between dangerous and benign polyps, doctors might inject a molecular-imaging agent targeting an enzyme that's concentrated in dangerous polyps. The enzyme itself would activate the agent by cutting it up and releasing particles that glow when light from a fiber-optic scope shines on the colon wall.



JOHN MACNEILL; SOURCE: UMAR MAHMOOD

to a cell's death, a process that biologists call apoptosis, is central to everything from embryonic development to aging; Apomate allows researchers to directly observe these events. By imaging cells' death throes, doctors might be able to see if a particular chemotherapy is successfully killing tumor cells, say, or more accurately assess damage caused by a heart attack.

Like many of the other new imaging agents in development, Apomate draws on the recent explosion in biologists' understanding of the details of the body's molecular processes. Among other findings, scientists have begun to unravel the precise details of apoptosis. It turns out that dying cells expose a binding site that's normally concealed. A naturally occurring protein then binds to that site, marking the cells for destruction by the immune system. Theseus created Apomate by engineering a synthetic version of the protein and linking it to a radioactive isotope that shows up under a scanner. When a patient is injected with Apomate, areas of the body where many cells are dying light up.

Apomate's potential market is large because of the myriad roles apoptosis plays in the body and the many ways doctors could use the agent. In human trials—ongoing in Europe now and likely to begin shortly in the United States—doctors are giving Apomate to lung cancer patients shortly after their first injections of chemotherapy. The aim is to determine within a day or two of the injections whether the drug is actually killing tumor cells. Patients who aren't helped by a particular chemotherapy drug can then be spared the wasted time and often debilitating side effects of the treatment—and can more quickly move on to explore other options. "Only 20 percent of these patients respond to the therapies, but 90 percent have side effects," explains Allan M. Green, chief technology officer at North American Scientific and Theseus. "To recognize early responses patient by patient is the most important near-term contribution we can make."

Theseus has also tested Apomate in more than 50 heart attack patients. Green says investigators have discovered a small subset of patients in whom apoptosis continues to take place in heart tissue even months after an attack. And researchers suspect these patients may be the most likely candidates for subsequent heart failure. If Apomate could help identify these patients, whose heart cells are continuing to die off, it could provide valuable clues as to who should be treated most aggressively—before their hearts begin to fail.

Researchers have also been using Apomate to try and identify unstable plaques in coronary blood vessels. It appears that the plaques most likely to rupture and cause heart attacks demonstrate a measurable amount of apoptosis as they crack and chip. If this work on imaging vulnerable plaques pays off, it could help doctors identify ahead of time some of the hundreds of thousands of people each year whose first indications of heart disease might otherwise be lethal heart attacks.

Doctors currently have ways of looking at structural changes in coronary arteries, but to find earlier danger signs "you need to know the biology," says Stanford University radiologist

Francis G. Blankenberg, a consultant to Theseus. Blankenberg says he envisions imaging schemes that look for apoptosis becoming part of a standard battery of tests for patients showing any kind of chest pain.

Noise *Reduction*

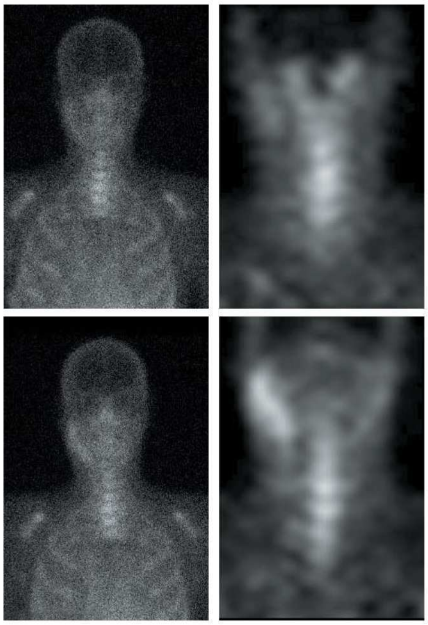
DESPITE ITS POTENTIAL, HOWEVER, molecular imaging is not without its technical challenges. For one thing, researchers are working hard to ensure that the images it produces are clear. Imaging agents are always on—always emitting radioactivity, like Apomate, or always glowing, in the case of some others. That works fine when there is an abundance of target molecules for the agents to bind to. The trouble is, sometimes the molecules characterizing a problem are so scarce that the few imaging agents that do reach and bind to them are lost in a haze generated by unbound agents floating nearby. That makes it hard to pick out a few precancerous cells in an otherwise healthy organ, for instance. And other times the agents collect in locations such as the liver, where they give off a bright but meaningless glow.

To address these problems, Northwestern's Meade and other researchers are inventing chemistry designed to keep the imaging agents invisible until they find their target molecules. "We're making molecular beacons that respond to physiological conditions," explains Meade. "They're off when injected, and only turned on by the presence of an enzyme target." That simple-sounding goal will nonetheless demand considerable basic research and complex chemistry.

Meade, for one, has come up with a novel scheme in which a target enzyme chews off the equivalent of a cap on the imaging agent, allowing it to beam out its signal. He hopes the approach will allow diagnosticians to use high-resolution MRI and computed-tomography scanners to probe ailments such as stroke, schizophrenia, and Alzheimer's disease.

Researchers at Massachusetts General Hospital are putting some of these same principles to work to improve the diagnosis of colon cancer—the second most common cause of cancer death in the United States, with more than 50,000 fatalities each year. Colonoscopy has helped physicians find colon cancer earlier. However, it can have difficulty dif-

Long view: Theseus Imaging's Allan Green says his firm's product could help fight both cancer and heart disease.
PHOTOGRAPH BY KATHLEEN DOOHER



Watching chemo work: A brighter glow after chemotherapy (bottom) than before (top) shows that drugs are killing tumor cells.

COURTESY OF THESEUS IMAGING

ferentiating between dangerous and more benign polyps. In a lab at Mass. General headed by Ralph Weissleder, scientists have found that an enzyme called cathepsin-B appears in higher concentrations in the most dangerous polyps than it does in nearby tissue and in other polyps.

Armed with this biological insight, the researchers designed a clever new imaging agent, taking advantage of the fact that cathepsin-B is an enzyme that cuts up specific proteins. They constructed the agent out of a fluorescent protein fragment attached to another molecule that keeps the fluorescence quenched. When the imaging agent finds cathepsin-B, the enzyme cleaves off the quenching arm, freeing up the probe to glow brightly. Since targets like cathepsin-B exist in very small quantities, turning off extraneous unbound agent molecules is like darkening the stars in a night sky to better spot a passing comet.

Because light scatters as it penetrates deep into tissues, it would be difficult to scan a human patient's colon optically from outside the body. But the technology could be paired with conventional colonoscopy. In the future, doctors may inject a patient with a fluorescent imaging probe designed to find the enzyme, and then examine the colon using a fiber-optic scope that picks up the fluorescence *(see "Molecular Colonoscopy," p. 67)*. This will allow doctors to distinguish between the different kinds of polyps in real time, with a minimally invasive approach, instead of having to cut out sample tissue and send it to a pathology lab, then wait days or weeks for the results.

As a next step, says Mass. General's Mahmood, the researchers are now performing test colonoscopies on lab mice using the new imaging agent. According to Mahmood, the technique could make it possible to avoid many colon biopsies in five to ten years.

In the near term, optical imaging could also help improve the accuracy of breast biopsies. These procedures now can miss malignant cells because it's difficult for physicians working off of two-dimensional mammograms to know exactly where in the breast to place their needles. Experts estimate that in the United States alone, some 50,000 to 100,000 breast biopsies each year don't find existing cancer cells—and so do not properly diagnose the women's cancers.

To address the problem, University of Wisconsin-Madison biomedical engineer Nimmi Ramanujam is exploiting the fact that biological tissues naturally fluoresce in response to stimulation by certain wavelengths of light—and that healthy and cancerous tissues fluoresce differently. Ramanujam scaled down optical imaging technology to create a tiny fiber-optic sensor that can be threaded right through a biopsy needle. When the doctor inserts the needle into the breast, the device sends light into the tissue and collects the fluorescence emitted by cells at the needle's tip; algorithms developed by Ramanujam analyze this fluorescence in real time to distinguish between the telltale optical signatures of healthy and cancerous tissues.

Ramanujam and her colleagues at the University of Wisconsin Medical School are already testing the technology on women undergoing breast cancer surgery and plan trials with women undergoing breast biopsy within the next year.

THE POTENTIAL TO PINPOINT MOLECULAR EVENTS INVOLVED IN A DISEASE RAISES A TANTALIZING POSSIBILITY: IN ADDITION TO DIAGNOSING A PROBLEM, WHY NOT ACTIVELY BLOCK IT?

Blurred *Boundaries*

THESE RAPID ADVANCES IN MOLECULAR imaging are helping to blur medicine's traditional boundary between diagnosis and treatment. That's because the potential to pinpoint molecular events involved in a disease, which is at the core of new imaging methods, raises an even more tantalizing possibility: in addition to diagnosing the problem, why not actively disrupt the process while you're at it?

Indeed, at Philips Medical Systems, a maker of traditional imaging devices, executives are increasingly excited about what they call the "see and treat" era. Says Josh Gurewitz, vice president of marketing in the nuclear-medicine division at Philips, "What sets molecular imaging apart is that we can not only identify and localize disease, we can now take this specific molecule and add a toxic payload."

Last year, just such a dual-purpose product won U.S. Food and Drug Administration approval for patients suffering from non-Hodgkins lymphoma who have not responded to other treatments. Made by San Diego, CA-based IDEC Pharmaceuticals (which will soon be called Biogen IDEC if a merger goes through as planned), Zevalin is a radioactively tagged antibody that ferrets out and binds directly to a specific protein on the rogue white blood cells that cause lymphoma.

Doctors inject the antibody, loaded with a harmless radioisotope, into a patient's body and monitor exactly where it goes, to make sure the tumor cells are safely treatable. Then they attach a different, more powerful isotope to the same antibody; once injected, it finds the cancer cells again and emits radiation to kill them.

Biotechnology companies have been dreaming about these sorts of two-pronged approaches for at least two decades. But it's taken progress in several disciplines, especially the chemistry required to snap the imaging and therapy components onto the same targeting molecules, to allow products like Zevalin to reach fruition. Now, however, the value of such new agents is becoming clear. "It's the treating that's so exciting," explains F. David Rollo, chief medical officer for Philips Medical Systems.

Indeed, IDEC is not the only pharmaceutical company bringing imaging technology into its product pipeline: both Amersham and GlaxoSmithKline are working with GE to develop improved imaging agents. But researchers say that while pharmaceutical companies seem to be intensely interested in molecular imaging, few are yet willing to fully embrace it. In the past, many drug companies avoided the imaging arena because markets—and profit margins—were perceived to be limited. Thanks in part to agents like Zevalin and Apomate, however, that perception is finally changing. And that could mean the boundaries between diagnosis and treatment will start to blur in the business arena, just as they have in the clinic.

IN THE PAST, MANY DRUG COMPANIES HAVE AVOIDED THE IMAGING ARENA BECAUSE MARKETS WERE PERCEIVED TO BE LIMITED. THANKS TO MOLECULAR IMAGING, THAT PERCEPTION IS CHANGING.

Companies "have realized that this is the future," says Washington University biomedical engineer Samuel Wickline, a cofounder of Saint Louis-based startup Kereos, which is developing molecular-imaging agents for cancer and heart disease. "It takes advantage of all we've learned in basic science, all we've learned in imaging, and all clinicians have learned. There is a quantum leap around the corner."

And as the traditional distinctions and business models are challenged, says Rollo, "You have to build new core competencies. In general, we've focused on imaging, not on blood tests and therapies. So we're partnering with a number of companies. We are evolving to change the way we do business to meet this technology." The hope for patients is that evolution will do for biopsy needles what it did for stone knives. TR

The Mouse That Glowed

Molecular imaging holds the promise of changing the way doctors practice medicine, but the field's biggest contribution might ultimately be in revolutionizing the way pharmaceutical companies make medicines. "Ninety percent of drugs in clinical trials fail because they have used animal models that aren't predictive," says Stanford University microbiologist Christopher Contag. Molecular imaging could put lab animals to better use—and put drugs on the market faster.

It's already happening: in early May, Cambridge, MA-based Millennium Pharmaceuticals won approval for a drug called Velcade to be used for combatting a rare form of blood cancer. During the drug's development, Millennium used optical imaging technology from Xenogen—an Alameda, CA, company Contag helped found—to highlight the key cancer pathways that Velcade was designed to attack. Millennium researchers engineered tumor cells to glow brightly under an optical scanner when the pathways were active, then transplanted those cells into lab mice. They were able to prove that Velcade worked as they'd hypothesized by comparing scans of mice who had and had not received injections of the drug; light beamed from the tumors of untreated mice, but not from those of animals who had received Velcade. Such direct confirmation that a drug is working can knock weeks or months off the development process. "In a few hours, we could get a readout of whether the drug was active in the pathway," says Geoff Ginsburg, Millennium's vice president for molecular medicine.

Engineered tumor cells transplanted into mice glow brightly when a cancer pathway is active (left). Injecting a potential drug blocks the glow, showing the drug works as expected.

Molecular imaging of animals could also help drug developers cut their losses on drug candidates that will ultimately fail to work or have undesirable side effects. Stanford research associate Ron Wong is using Contag's optical technologies to explore the behavior of compounds being considered as treatments for jaundice in newborns; he evaluates the compounds by testing them in mice that have been genetically engineered to produce a glowing protein that indicates when genes involved in jaundice are activated. After a recent round of experiments, Wong points to a slide showing a mouse with a considerable amount of light emanating from the gut area. In this case it means the would-be drug is triggering cellular activities that could cause side effects—and is thus a poor candidate.

With startups like Xenogen partnering with more pharmaceutical firms, and companies such as Merck and Novartis developing significant in-house molecular-imaging groups as well, drug developers should find that their view of what works—and what doesn't—keeps getting better.

COURTESY OF MARIA HOTTELET, SHENGHUA WEN, MARK MANFREDI, AND MICHAEL HENRY

THERE'S NOT ENOUGH ART IN OUR SCHOOLS.

NO WONDER PEOPLE SAY "GESUNDHEIT" WHEN YOU SAY

"TCHAIKOVSKY."

Peter Ilyich Tchaikovsky endured many setbacks, not the least of which was a blind barber.

If one were to make a quick list of the world's favorite composers, despite his relatively recent vintage Peter Ilyich Tchaikovsky would be on it. After all, he did compose *Swan Lake*, which is perhaps the most famous ballet of all time. And there can't be more than just a handful of ballet companies that don't perform *The Nutcracker* every Christmas.

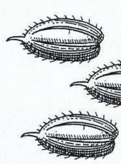


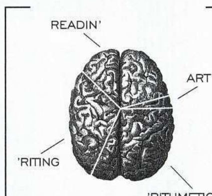
Fig. 1 Pollen

Causes watery eyes. Much like Tchaikovsky's composition "Romeo and Juliet."

Indeed, this great Romantic composer should be so immortalized. As a young man, he pursued a career in music at enormous personal risk and against his own father's advice. His mild temperament combined with his tendency to work too hard left him with insomnia, debilitating headaches and hallucinations. On top of that, Tchaikovsky's composition teacher never liked his work, even after he became world-famous.

Setbacks like these could have finished a lesser man. Instead, they informed his work, which remains some of the best loved in history. Yet some kids will still confuse Tchaikovsky with a nasal spasm.

Why? Because the arts are slowly but surely being eliminated from today's schools, even though a majority of the parents believe music and drama and dance and art make their children better students and better people.



Someone isn't getting their recommended daily allowance of art.

To help reverse this disturbing trend, or for more information about all the many benefits of arts education, visit us at AmericansForTheArts.org. Or else Tchaikovsky could seem like just another casualty of allergy season.

ART. ASK FOR MORE.

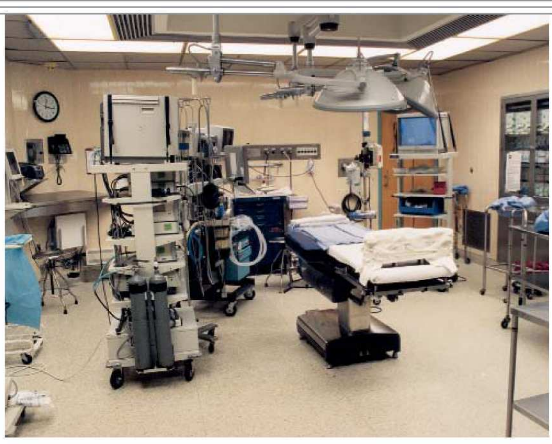
Team players: Nurse Marie Egan, surgeon David Rattner, and anesthesiologist Warren Sandberg say the new operating room's design helps them work better together. In a traditional O.R. (inset) staff members often get in each other's way.

An operating room that encourages efficiency, teamwork, safety, and comfort? Welcome to Massachusetts General Hospital's

O.R. OF THE FUTURE

DEMO

Today's operating rooms are rats' nests of equipment and wires, overpopulated with doctors and nurses who must constantly elbow past one another to actually see what's happening with a patient, adjust an instrument, or read a monitor. Not necessarily the ideal environment for the staff, let alone for the person on the table. But at Boston's Massachusetts General Hospital, a nonprofit consortium called CIMIT (for Center for Integration of Medicine and Innovative Technology) is building tomorrow's operating room, and it looks a whole lot different.



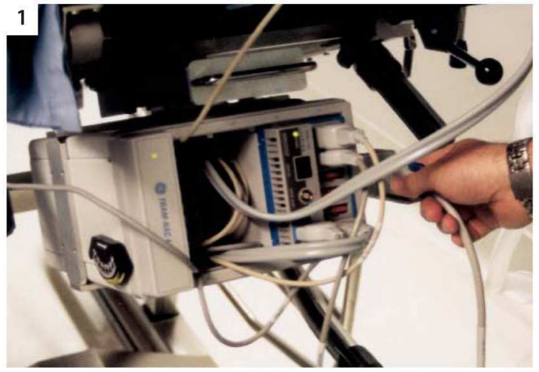
The space itself—actually a suite of rooms—is open and airy, with elbow room to spare. Strategically placed cameras and monitors afford each member of the surgical team a clear view no matter how crowded the room gets. Equipment is neatly organized and designed for seamless integration. A computer keeps track of the doctors' whereabouts via radio-frequency-and-infrared tags, and eventually each piece of equipment could be tracked the same way—meaning nurses won't have to go searching for critical devices in the middle of surgery, and doctors won't have to open patients back up to retrieve wayward clamps and sponges.

"The goal is to make it the safest operating room in the world, and also the most efficient," says David Rattner, the surgeon who heads the Operating Room of the Future program. Rattner, along with surgical nurse Marie Egan—the project's manager—and Warren Sandberg, the program's director of anesthesia, showed *Technology Review* senior editor Rebecca Zacks just what the team is doing to reach that goal.

PHOTOGRAPHS BY JOHN SOARES

1. One of the key ways the new operating suite improves efficiency is by allowing processes that would normally happen sequentially—setting up equipment, putting a patient under, and so forth—to happen in parallel. Procedures start in a small room off the main operating room, Marie Egan explains. "Patients actually go to sleep and are intubated here. Anesthesia can be doing their piece synchronously with the room being prepared. That could be 20 minutes of process time in a regular O.R." Warren Sandberg adds, "The other thing that's key about this is that we have the patients monitored from the beginning of their anesthetic all the way through to the end, without ever taking the monitors off." Pointing out a beige box under a bed's head support, he adds, "We accomplish that by attaching the monitors to the bottom of the bed."

2-4. So the monitors can travel with the patient—and so nobody has to hoist a patient from gurney to table—the bed is a modular, mobile system. The cushioned top can be transferred from a wheeled trolley (2) onto a large electromechanical post in the main operating room (3). All in all, Sandberg says, wheeling a sleeping patient into the operating room, docking the bed onto the post, and plugging the monitors into the main anesthesia computer (4) takes only 75 seconds.

1


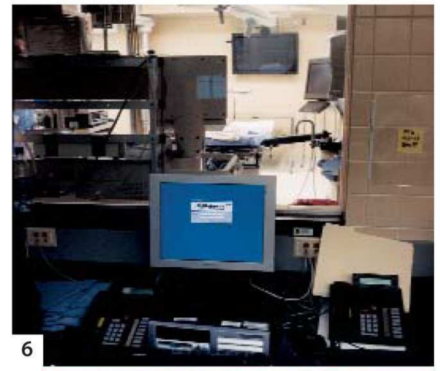
2


3


4


5

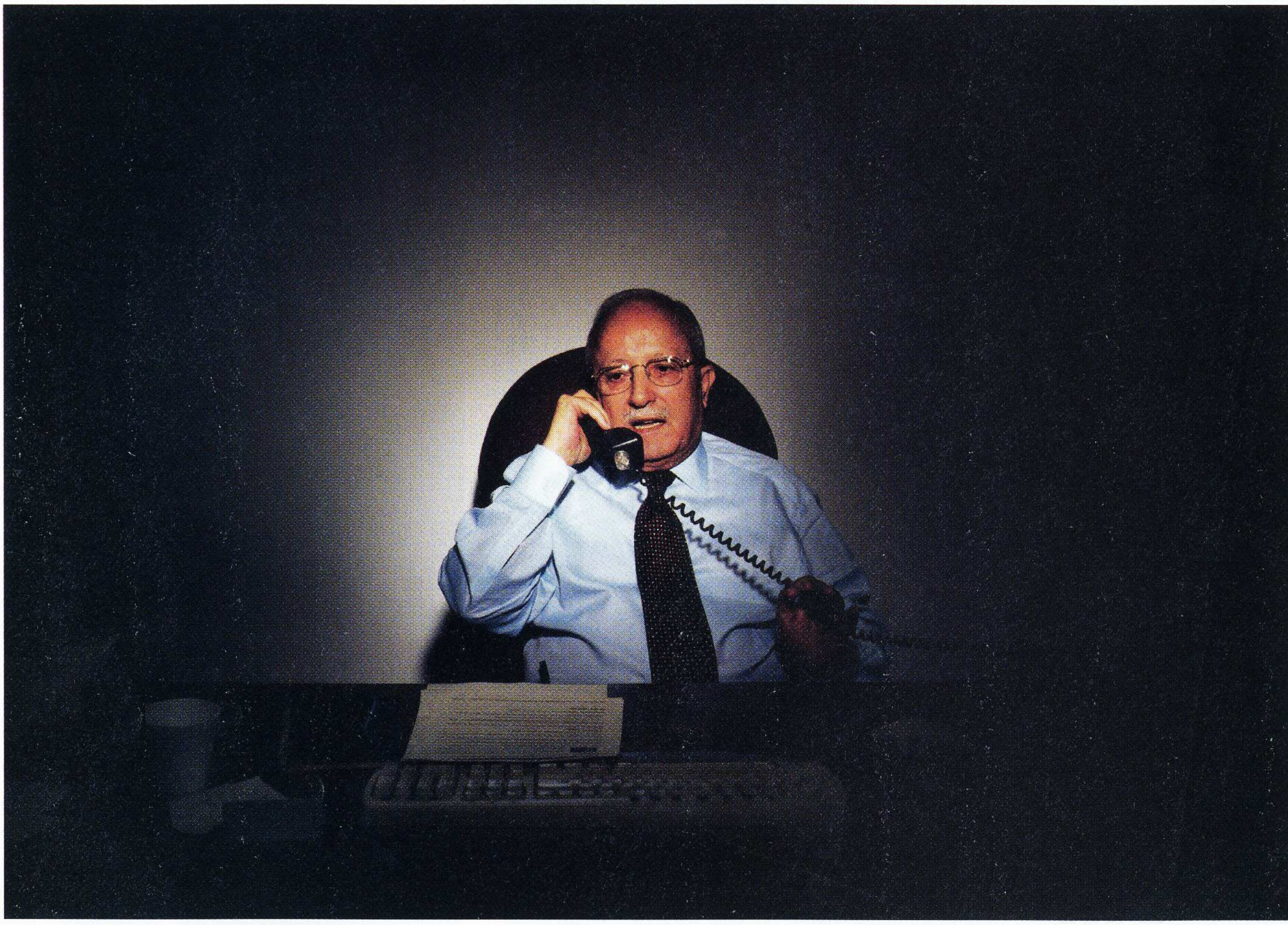

5. Since the pace is so fast in this O.R., ease of use is key. David Rattner pulls forward a boom-mounted cart loaded with equipment, all of which is integrated, he says. "That allows nurses to control stuff with one switch rather than having to turn each one on individually and connect them and worry about whether they're connected right. Because it's intimidating to be swamped with a lot of high-tech devices. Here, they're all mounted together, they're all controlled together, and so it makes it a little bit less stressful for the nurses."

6


7


6-7. To make things less stressful for the doctors, the O.R. suite includes a "control room" off the main operating space where they can make calls and write up notes (6). "You don't want your surgeons wandering off between cases," says Egan. "In your inefficient environment, you couldn't blame them. If you have 35 to 40 minutes between cases, that's a lot of time in a surgeon's life. They can nip up to the office to see a patient, go do something." To measure how efficiently work gets done in this new environment, doctors' movements are tracked and timed via a radio-frequency-and-infrared tag (7). Tags might one day reduce medical errors by tracking drugs, or the instruments that can accidentally be left in patients—making things less stressful for just about everybody.

WHERE TECHNOLOGY COLLIDES WITH SOCIETY, BUSINESS, AND PERSONAL LIVES



By Erika Jonietz | Photograph by Beth Perkins

TECHNOLOGY CAN'T TAME TERROR

Isaac Yeffet

POSITION: Founder, Yeffet Security Consultants, an airline security firm

ISSUE: Air travel screening. The U.S. Transportation Security Administration wants to increase the use of technology to improve airline security. But will it really help?

PERSONAL POINT OF IMPACT: Former head of global security for Israel's El Al airline

TECHNOLOGY REVIEW: How can technology make security screening for air travel safer?

ISAAC YEFFET: Technology works well when used to help qualified and well-trained human beings. Technology can never replace the human being. And in the U.S.A., technology is the only security that we have and rely on for baggage and carry-on screening in our airports. The people we have are not qualified, and the technology we have at the airports around the country—which has a 35 percent false-alarm rate—is the wrong concept.

TR: What kind of technology do U.S. airports use today?

YEFFET: The majority is in vision, with the CTX, a chemically blind x-ray machine that we see at airports. It can drive us crazy by identifying chocolate, cheese, pizza, cakes, et cetera, as something suspicious. Thirty-five percent of the time we get a false alarm, so you have either to rescreen luggage or open it for hand search. When we know that we send to U.S. air carriers alone 1.5 billion pieces of luggage and carry-ons every year, it comes to between 1.2 and 1.3 million pieces of luggage a day that we have to rescreen or hand search. Now this is wrong, because you cannot drive the screeners crazy by [making them open] luggage after luggage to find out there is no explosive. One of the biggest enemies of security is routine. After a while, it becomes a routine, and the screeners will not pay attention anymore. They are not even trained to do a professional hand search, especially when we deal with a sophisticated enemy who knows how to conceal explosives in a double bottom.

TR: The screeners seem like our primary line of defense, then. How are they hired, post-September 11?

YEFFET: We have 55,000 screeners around the country. By law, a screener cannot be hired without a criminal background check. Now, we found out that 22,000 security guys were hired without any background security check—after September 11. Millions of passengers, their

lives are in the hands of these people. At JFK alone, in May they found that 50 security people have a criminal record. This is not the security that we need and deserve in this country.

TR: So how do you pick and train people properly for this job?

YEFFET: First, by hiring only qualified people, minimum high-school education, speaking both English and another language. Then we train them for days, not hours, and train them on the job, and then test them, test after test. I used to do thousands of tests every year when I was head of security for El Al. And I didn't do simple tests by sending somebody with a fake explosive through the x-ray machine to find out if the screener can stop it. We did complicated ones where a passenger has to go with the luggage to the check-in to be interviewed by El Al security, and they have to determine if this is a bona fide passenger or suspicious passenger.

Unfortunately, the intelligence organizations cannot cover all the terrorist plans or activities, and therefore the security of the airline should act also as an intelligence agency. As an example, the employees of the ticket office and the reservations department have to be trained to send information to the security department of the airlines to tell them who came to buy tickets at the last minute, who paid cash, who bought a one-way ticket, and how they behaved. Nationality and so on and so on. Here, we don't train anybody. We rely only on the low level of technology that exists at the moment at our airports.

TR: Is there any technology in use now that's helpful?

YEFFET: If you go to Newark airport, Continental Airlines has a high level of security on the flights to Tel Aviv [in Israel] and to Amsterdam—fantastic security. They have a machine that within three to five seconds can tell you if your passport is fake or real. Why can they have it and other air carriers cannot? Why cannot we do this in other airports? Yes,

it will cost them money, but this is the richest country in the world.

TR: What about CAPPS II, the Computer Assisted Passenger Pre-Screening Program, which the U.S. Transportation Security Administration wants to implement? It's designed to gather the kind of data you've mentioned, such as nationality and method of payment, and analyze which air travelers might be risks.

YEFFET: Every small thing can help. The question is, is this the solution? Definitely not. Let's assume you bought a one-way ticket, or you paid cash, which is not normal in the U.S. And it is in the computer. Who will interview you? Who will do the investigation? I want to know. Who will use the information, when we do not interview passengers? Who will determine who is suspicious, when we only train people how to operate x-ray machines and do body searches only when the alarm goes off?

TR: If the CAPPS II system has already identified which passengers are the risks, is it still necessary to question everyone?

YEFFET: Every passenger should be questioned. Most of the passengers are bona fide. I need to question them maybe two minutes, and they will be released. Now, say somebody is coming with a passport from Syria, Sudan, Iran, where we know that they support terrorist organizations with millions and millions and millions of dollars every month. Why cannot I treat this kind of passenger differently, not hurting his dignity, but to make sure he is not a risk? If he is bona fide, he has to appreciate the fact that I am checking him, because it will be also for his safety.

TR: This raises the question of privacy, which some activists say this new computer system will invade.

YEFFET: Privacy is important, but the lives of innocent people are much more important. After September 11th, we all are willing to give up some of our privacy and convenience to save lives. I have done many surveys for the media around the country in the last 17 years. We interviewed thousands of passengers. All of the people I interviewed are ready to give up some privacy for security—if we can prove that they really are more secure.

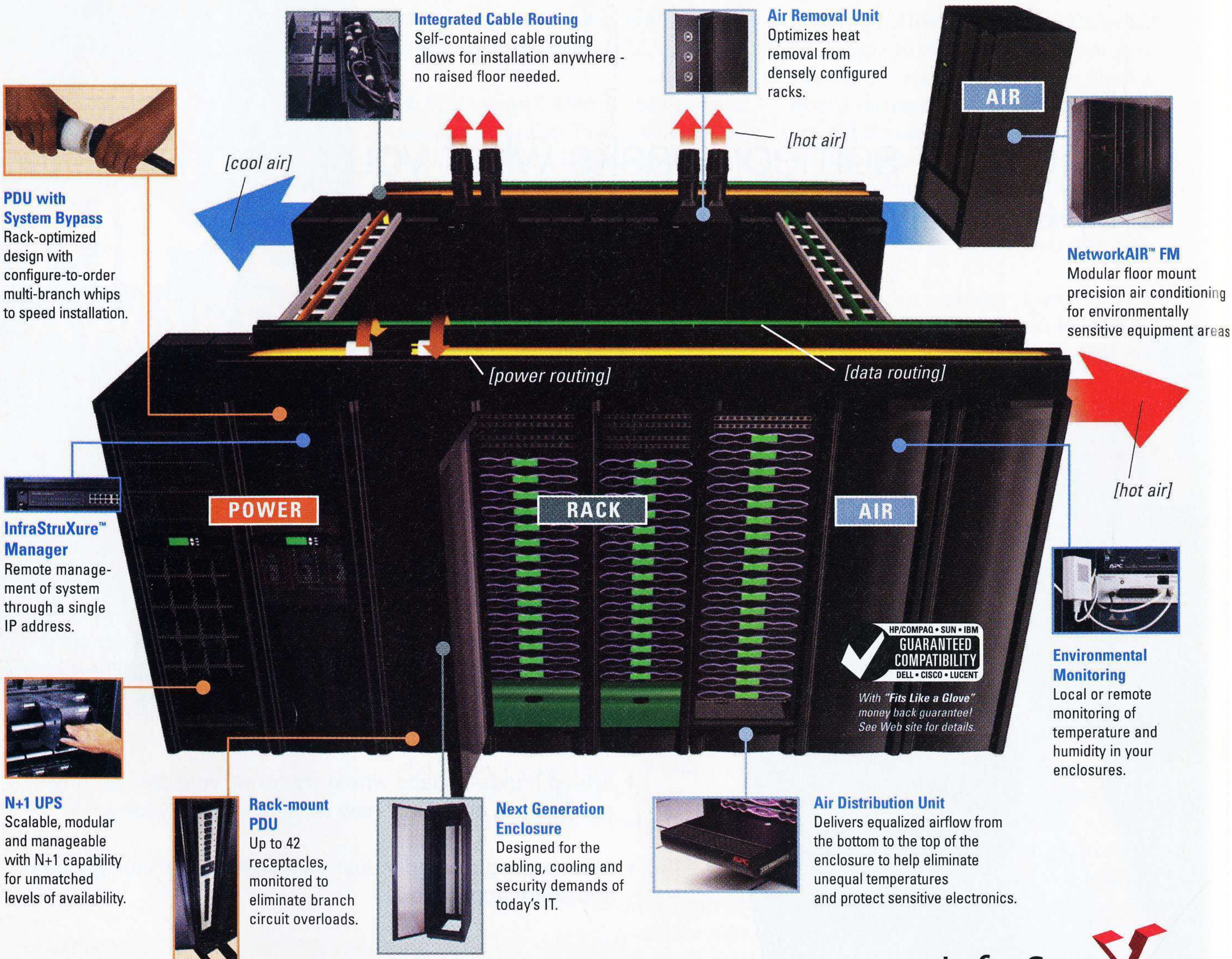
Now, what is privacy? I am not going to ask who is your boyfriend, how many children you have—questions that are nonsense. I am going to ask about security. And you will understand that my concern is your safety and security, because I am staying on the ground, and you are taking the flight.

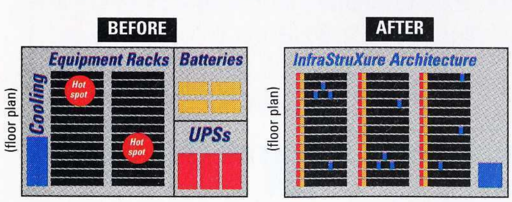
"Technology works well when used to help well-trained human beings. It cannot replace the human being; it only can help. If we rely on technology alone, I'm afraid that at the end, only the enemy will celebrate."

TR: But some of the checks CAPPS II proposes to make—for instance, into financial data or criminal records—seem to enter those sensitive areas.

YEFFET: This is wrong, wrong, wrong. Stop digging in the heart of everybody. We are looking for terrorists and not for somebody that owed money or didn't pay taxes. I am not worried about people smuggling money or whatever. I am worried about explosives and weapons. These are the terrorists that I'm looking to arrest on the ground before it will be too late. If we start to investigate anyone who drove while he was drunk, anyone who hit his wife, anyone who stole from the IRS, you will have lines 10 times worse than today. Stop it: concentrate on terrorism and security. And leave the nonsense. This is not aviation security.

Technology cannot replace the human being; it only can help. And if we rely on technology alone, I'm afraid that at the end, only the enemy will celebrate. I don't want the enemy to celebrate any more. Let us build a proactive security system that will rely on the human being with the help of the technology, but not only technology, technology, technology. TR


Integrated Cable Routing
Self-contained cable routing allows for installation anywhere - no raised floor needed.
Air Removal Unit
Optimizes heat removal from densely configured racks.
[hot air]
[cool air]
AIR
PDU with System Bypass
Rack-optimized design with configure-to-order multi-branch whips to speed installation.
NetworkAIR™ FM
Modular floor mount precision air conditioning for environmentally sensitive equipment areas
[power routing]
[data routing]
[hot air]
POWER
RACK
AIR
InfraStruXure™ Manager
Remote manage-ment of system through a single IP address.
HP/COMPAQ • SUN • IBM
GUARANTEED COMPATIBILITY
DELL • CISCO • LUCENT
With "Fits Like a Glove" money back guarantee! See Web site for details.
Environmental Monitoring
Local or remote monitoring of temperature and humidity in your enclosures.
N+1 UPS
Scalable, modular and manageable with N+1 capability for unmatched levels of availability.
Rack-mount PDU
Up to 42 receptacles, monitored to eliminate branch circuit overloads.
Next Generation Enclosure
Designed for the cabling, cooling and security demands of today's IT.
Air Distribution Unit
Delivers equalized airflow from the bottom to the top of the enclosure to help eliminate unequal temperatures and protect sensitive electronics.


BEFORE
Equipment Racks
Batteries
Cooling
Hot spot
Hot spot
UPSs
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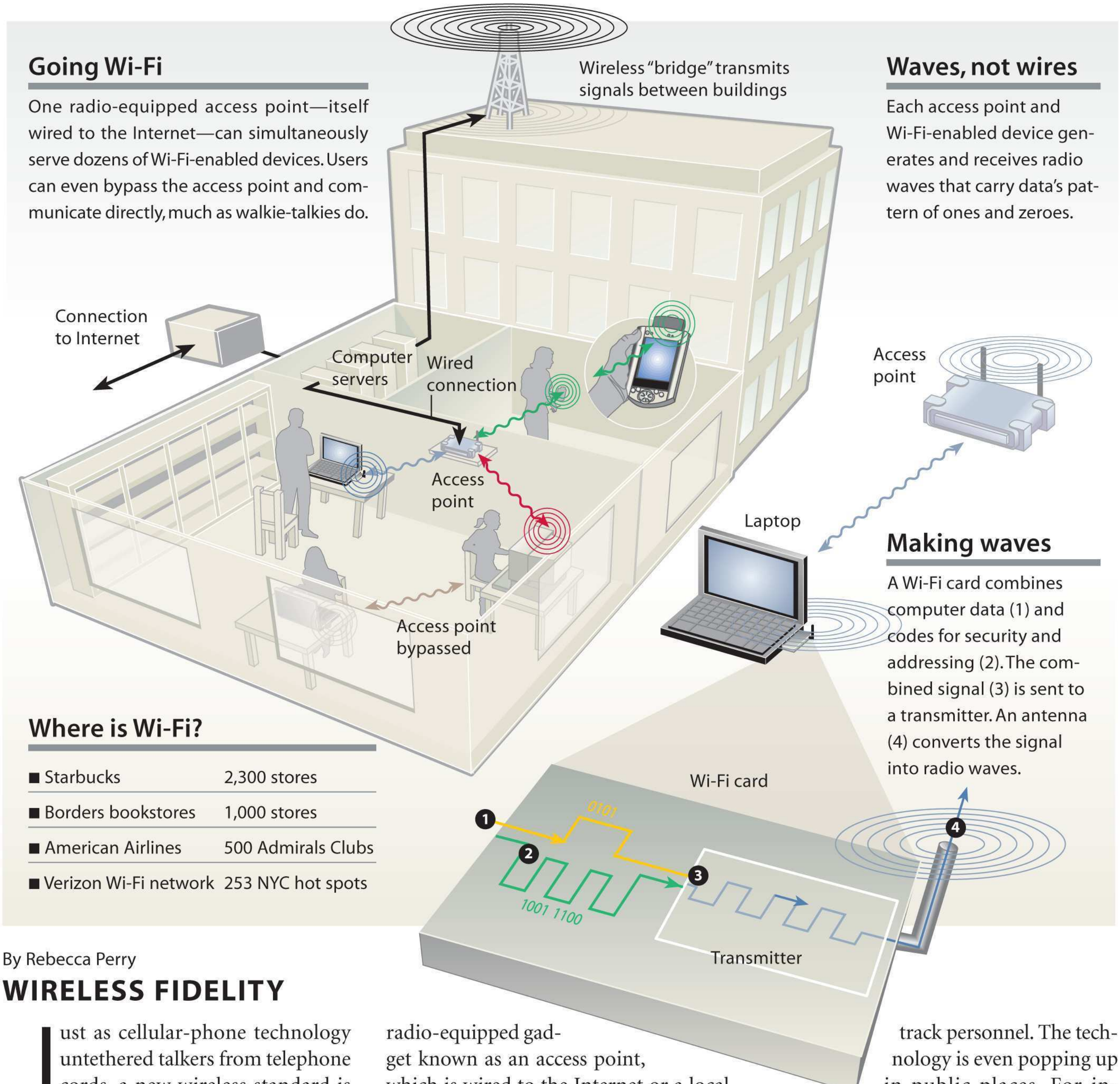
AFTER
InfraStruXure Architecture
(floor plan)



Going Wi-Fi

One radio-equipped access point—itself wired to the Internet—can simultaneously serve dozens of Wi-Fi-enabled devices. Users can even bypass the access point and communicate directly, much as walkie-talkies do.

Waves, not wires

Each access point and Wi-Fi-enabled device generates and receives radio waves that carry data's pattern of ones and zeroes.

Making waves

A Wi-Fi card combines computer data (1) and codes for security and addressing (2). The combined signal (3) is sent to a transmitter. An antenna (4) converts the signal into radio waves.

Where is Wi-Fi?

■ Starbucks	2,300 stores
■ Borders bookstores	1,000 stores
■ American Airlines	500 Admirals Clubs
■ Verizon Wi-Fi network	253 NYC hot spots

By Rebecca Perry

WIRELESS FIDELITY

Just as cellular-phone technology untethered talkers from telephone cords, a new wireless standard is freeing computer users from network cables. Wireless Fidelity, a.k.a. Wi-Fi or 802.11b, uses radio transmissions to connect computer devices to a network—or to each other—at distances of up to about 100 meters. With Wi-Fi, you can surf the Web, grab work files from your company's server, and check your e-mail—all without having to plug into a network jack.

The two basic components of a Wi-Fi network are a computer device outfitted with a low-power radio and another radio-equipped gadget known as an access point, which is wired to the Internet or a local network. The two communicate with each other over a free slice of the radio spectrum reserved for consumer use and inhabited by microwave ovens and cordless phones.

The freedom and mobility Wi-Fi offers appeal to a wide range of users. At home, Web surfers can download music on the backyard patio. Businesses and universities can use the technology to avoid the high costs of wiring up offices and dormitory rooms. Police and other emergency-services providers will soon be able to link Wi-Fi with GPS systems to track personnel. The technology is even popping up in public places. For instance, NYCwireless, a community organization, offers free wireless Internet access to all comers in a downtown park. And many retail outlets are seeing Wi-Fi as an inexpensive marketing gimmick. By offering wireless connections for little or no cost, businesses like Starbucks and Borders are demonstrating that liberating people from their digital tethers actually makes them linger longer.

For an animated version of this illustration, go to www.technologyreview.com/visualize/.

FULL OF (SOY) BEANS

It has been a pleasure and a privilege to voice my opinions on the increasingly important and often misunderstood subject of intellectual property. But after nearly three years writing this column, I'm taking a break from punditry to devote more time to reporting and a new book project.

I've argued here—and in my book *Owning the Future*, which spawned this column—that in allowing corporations to amass ever broader, exclusive proprietary rights to entire areas of knowledge, we are making some grave mistakes that we will almost certainly come to regret.

A recent European patent ruling perfectly underscores the point. The case involves an audacious patent by the plant biotechnology giant Monsanto claiming exclusive rights over all genetically engineered soybeans—yes, you read it right—created by the company's or any other method. In the latest surprise development, after eight years languishing on appeal, the patent was upheld as valid by the European Patent Office.

Bottom line: this patent is full of beans.

Such a broad patent does nothing to provide incentive for new innovation. Instead, it does the precise opposite, shutting off potential competitors' efforts in the face of the time-limited monopoly. Of course, the situation is all the more worrisome when the monopoly involves a crucial world food crop. Even the U.S. Department of Agriculture could see this problem when a small Wisconsin-based firm called Agracetus was granted a close cousin to the soybean patent in the United States a decade ago—one claiming rights to all genetically engineered cotton.

In that case, the USDA stepped in, contested the patent, and ultimately helped convince the U.S. Patent Office to overturn it. Ironically, a major force backing the patent's overturn at that time was Monsanto. The company's 292-page legal memorandum argued persuasively that the broad Agracetus patent should be revoked. But that was before Monsanto's 1996 acquisition of Agracetus's plant biotechnology assets—including its European soybean claim. From then on, Monsanto defended the soybean patent, deciding that a monopoly on genetically engineered crops wasn't so bad after all.

It is worth noting that Monsanto and Agracetus structured their broad claims around a gizmo called a "gene gun," though neither actually invented this device for inserting genes into plants like soybeans and cotton. The technology was developed by a team at Cornell University. Thus, the multibillion-dollar question is this: just because Agracetus was the first to use this tool to blast gold beads covered with DNA into soybeans, why should that entitle them to demand royalties from another firm inserting different genes into different soybean varieties by different means? Put another way, why should one firm that accomplished one significant but small step be able, for two decades, to control innovation over an entire crop species? But that, alas, is precisely what the firm is trying to do (and what it has done in Europe): its patent governs all genetically modified soybeans engineered by its or any other method. And we're talking about a lot more than tofu and soy sauce here. Soybeans are the second-largest U.S. crop after corn, the world's foremost source of protein and oil, and a major component of livestock and poultry feed, a key ingredient in the food chain.

Monsanto already controls virtually the entire market for genetically engineered soybean seeds. And crops sown from Monsanto's genetically engineered seeds now cover more than half of the 72 million hectares on the globe that are planted with soybeans. Patents aren't the only reason for this monopoly, but with the European patent upheld, Monsanto's monopoly concentration will likely only increase in the future.

Patents like this one are utter folly. Patent and copyright law has a vital role to play in the emerging global information economy. But the system was designed to provide incentive for new inventions; it was never intended to hand out monopolies on whole areas of research. Overly broad patents will lead to monopolies where we neither need nor want them. Similar problems are cropping up across the high-tech landscape: patents are literally killing AIDS victims in Africa by denying them access to affordable medicines even though we know how to make the drugs cheaply; absurdly broad e-commerce patents are tangling the World Wide Web; and overly expansive copyright laws threaten our ability to share information.

Parting prose from a patent pundit: from soybean seeds to AIDS drugs, quit issuing broad patents that allow corporate bullies to grab intellectual-property monopolies on our collective future.

The kinds of excesses we've been seeing lately need not be foregone conclusions. The trick is for those at the high-tech frontier to help our legislators be farsighted in thinking about the public's stake in intellectual property, building a system that equitably rewards new developments while at the same time providing a healthy environment for innovation. The good news is that many groups have begun to meet this challenge; among them, Creative Commons, the Public Library of Science, and Washington, DC-based Public Knowledge (I'm on their advisory board) are trying to map out a role for the public, just as the vibrant open-source-software community is doing much to stem the tide of proprietary control over software code.

Once we get beyond inane debates about whether intellectual property is "good or bad," the task of setting reasonable limits on proprietary rights is not as hard as it may sound. But there's a clear first step: quit handing out absurdly broad patents that allow corporate bullies to grab intellectual-property monopolies on our collective future. TR

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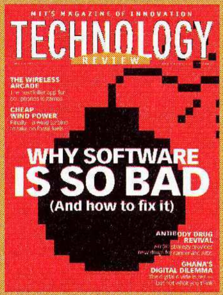

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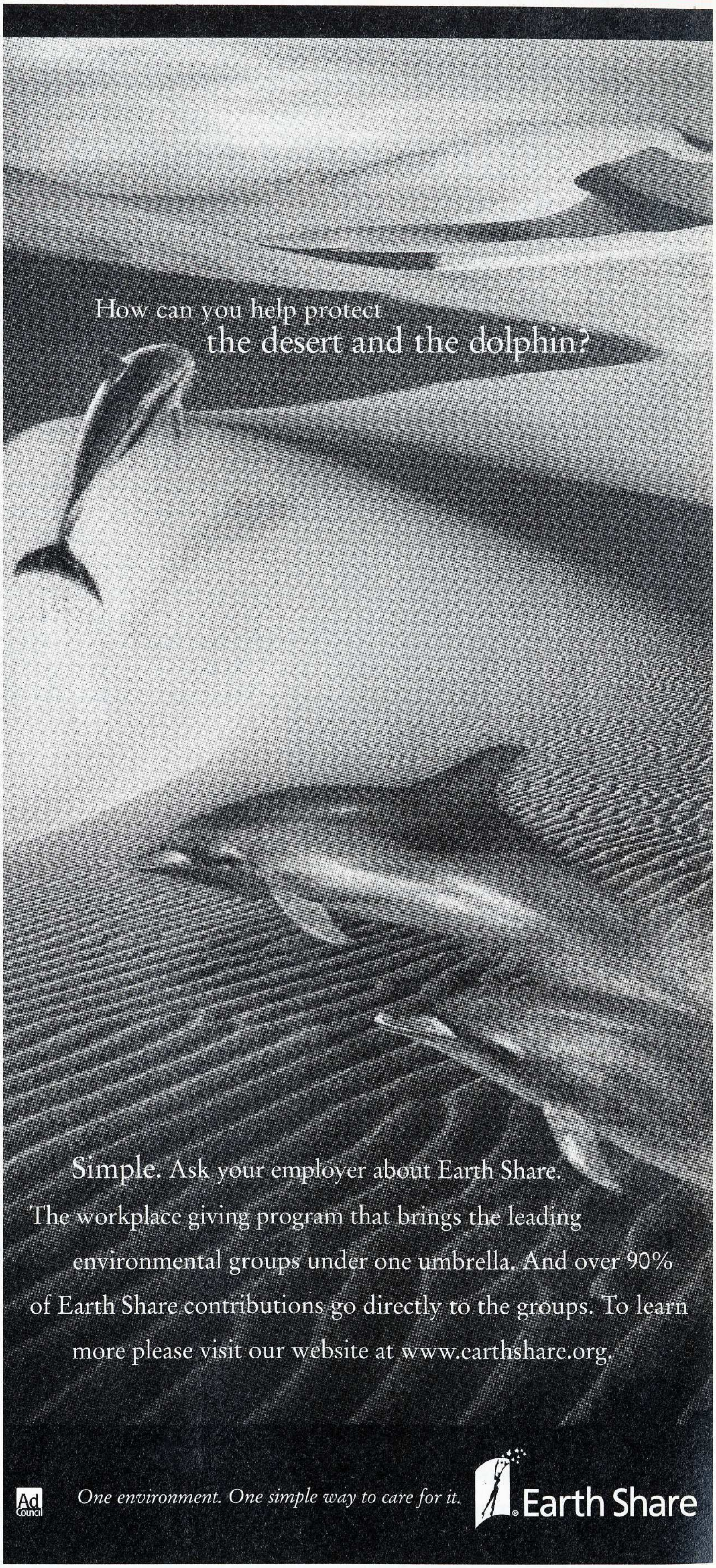

The Computerized Bulletin Board System's hardware in 1980.

FROM BULLETIN BOARDS TO BLOGS

Online communities thrived long before the advent of Web logs

Web logs, or "blogs"—easy-to-update personal online journals—have swept the country in recent years. A popular blog application, Blogger, owned by Mountain View, CA-based Google, has more than a million registered users. But the blog isn't the first online community; that was created a quarter-century ago.

During a severe Chicago snowstorm in January 1978, IBM systems engineer Ward Christensen telephoned his friend, electronics technician Randy Suess, to chat. They were both members of the Chicago Area Computer Hobbyist's Exchange, a local club for tech enthusiasts who, in that pre-PC era, had built their own home computers. Christensen and Suess started discussing the club newsletter, which was always looking for articles. The previous year, Christensen had written a pioneering computer program, later called "Xmodem," that allowed people to exchange files over phone lines via their brand-new modems. Christensen mused about how convenient it would be if club officers could simply download articles to a central computer, then print them for inclusion in the club newsletter. He and Suess soon began speculating about a system that would serve the same function as the club's corkboard, where members posted index cards for one another to read.

In the heat of inspiration, Christensen tackled the software and Suess the hardware. Within just two weeks, the Computerized Bulletin Board System (CBBS) was born. Users would call up a computer at Suess's house, which, thanks to his innovations, automatically booted up Christensen's software when the phone rang. Browsing and posting messages required a few simple keyboard commands. The system became wildly popular, with hundreds of users discussing all sorts of subjects, and Christensen was soon inundated with requests for the BBS software. He still considered it strictly a hobbyist phenomenon, however, and didn't think his employers at IBM would be interested. But even without corporate backing, BBSs spread like wildfire during the 1980s and into the '90s.

The rise of the Internet, though, brought the BBS era to a close. Many of its functions were taken over by e-mail, online newsgroups, and later, blogs. The original CBBS finally shut down in the early 1990s after connecting with more than a quarter-million callers. Christensen, still at IBM, modestly asserts that he and Suess were just in the right place at the right time: "It was not revolutionary, just evolutionary." —*David Rapp*

COURTESY OF FRANK DERFLER

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